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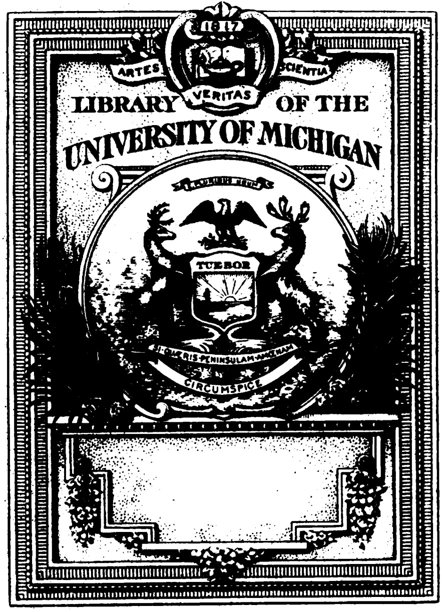

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DESIGNED FOR A TEXT BOOK

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BY JOHN JOHNSTON, A. M.

PROFESSOR OF NATURAL SCIENCE IN THE WESLEYAN UNIVERSITY.

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PROFESSOR OF CHEMISTRY, MINERALOGY, AND NATURAL PHILOSOPHY

IN BOWDOIN COLLEGE, BRUNSWICK, ME.;

DISTINGUISHED NO LESS FOR HIS PERSONAL VIRTUES

THAN

AS THE AUTHOR

OF THE FIRST AMERICAN WORK ON MINERALOGY AND GEOLOGY;

The following Pages are Respectfully Inscribed,

IN TOKEN OF THE DEEP SENSE OF OBLIGATION ENTERTAINED

BY HIS FRIEND AND FORMER PUPIL,

JOHN JOHNSTON.

Definitions of Chemistry.

THE following Definitions of Chemistry, except the last, are taken from Hare's "Compendium," page XVI.

Thomson defines Chemistry to be "the science which treats of those events or changes in natural bodies, which are not accompanied with sensible motions."

Henry conceives that "it may be defined, the science which investigates the composition of material substances, and the permanent changes of constitution, which their mutual actions produce."

According to *Murray*, "it is the science which investigates the combinations of matter, and the laws of those general forces by which these combinations are established and subverted."

Brande alleges "that it is the object of Chemistry to investigate all the changes in the constitution of matter, whether effected by heat, mixture, or other means."

According to *Ure*, "Chemistry may be defined that science, the object of which is to discover and explain the changes of composition that occur among the integrant and constituent parts of different bodies."

The definition given by Berzelius, is as follows:—"Chemistry is the science which makes known the composition of bodies, and the manner in which they comport with each other."

The following is from J. BARRATT, M. D., of Middletown, Ct.:

"Chemistry is the science which unfolds compound bodies, and makes known to us the laws that combine and regulate the various forms of matter, and their nature and properties. In other words, it is the science of decomposition and recomposition of elementary substances, in the operations of nature or of the laboratory, by the agency of affinity, light, heat, and electricity."

EXTRACT FROM THE

ADVERTISEMENT TO THE FIRST EDITION.

The preparation of the following pages was undertaken by the advice of the late lamented President of the Wesleyan University, with the primary design of providing a suitable Text Book on Chemistry, for the use of the annual classes in that institution.

There are indeed already before the public many excellent works on this branch of science, the great merits of which the subscriber is happy to acknowledge; but he long since became convinced, from his experience in teaching, of the need of a work of a little different character, for the special use of students in our higher seminaries of learning, as a text-book. The object of a great majority of students, even of those who pursue a collegiate course, is, not to make themselves familiar with minute details of facts or processes of manipulation, but to understand the great principles of the science, and the leading facts which serve for its foundation. To facilitate in the accomplishment of this purpose is the object of the present work. In preparing it, the excellent "Elements of Chemistry" of the late Dr. Turner has been adopted as the basis, and all of that work incorporated in it which was suited to our purpose. His arrangement has been uniformly followed, with a few unimportant exceptions, which it is not necessary here to particularize. This arrangement, on the whole, is considered the best that has ever been proposed.

The part of Dr. Turner's work omitted is taken up chiefly with details of facts and discussions of opinions and theories, which is indeed important in a work designed for the general student, but which would be out of place in a book prepared expressly to be used as a text-book. Its place, however, has been in part supplied by matter compiled from various other sources, so that the work is thought to be sufficiently large for the ordinary use of students, as the study of this science is usually pursued in this country. It has constantly been an object, while the work should be true to the science, and present in true proportion all its important features, to make it at the same time as practical as possible; to lead the student to apply the principles he learns to the solution of natural phenomena, or processes he may witness in the arts.

ADVERTISEMENT

TO THE SECOND EDITION.

In the present edition the work has been carefully revised, and indeed re-compiled from the seventh edition of Turner's, and many additions made to adapt it to the advancing state of the science. The chief alteration, however, that has been made in the part on Inorganic Chemistry, consists in the transfer of the section on Crystalography from the chapter on salts to that on chemical combinations. The reasons for the change it is believed will be obvious.

The third part on Organic Chemistry has been entirely re-modeled and it is hoped will be found much better adapted for the purposes of instruction, in the present advanced state of this highly interesting and important branch of the science. The new matter introduced has been compiled entirely from the last edition of Turner's work, edited by Liebig and Gregory, Thomson's Chemistry of Organic Bodies, and the recent work of Kane.

The extracts from other authors are always introduced in their own language, except in cases where it was necessary to make some little change to incorporate the extract the better with the passage with which it comes in connection. In a few instances the names of authors are introduced in the text. To avoid the necessity of constantly introducing quotation marks and references, a list of the authors which have been used will be given at the close of this advertisement. The compilation, however, has been chiefly made from the eleven first mentioned, the others having been referred to, with a few exceptions, only for facts or principles.

To facilitate in the acquisition of the science, the text is divided into paragraphs, and numbered; and references to important facts and principles introduced as frequently as they seemed necessary. As in many institutions so much time cannot be devoted to this science as would be requisite for a thorough study of the whole work, the less important parts have been printed in smaller type, which may be omitted on the first reading. The intelligent student, however, it is hoped, will not be satisfied without a perusal, at his hours of leisure, of the whole work.

To adapt the work for the use of the younger class of learners, a series of questions to the first three parts has been prepared, which, however, is designed to be bound in a pamphlet separate from the body of the work itself.

A few pages only on Analytical Chemistry have been introduced, merely to illustrate the design and nature of this branch of the science.

It only remains for the compiler to acknowledge his obligations to several kind friends, who have favored him with important suggestions, that have contributed considerably, it is believed, to the improvement of the work.

J. J.

Wesleyan University, *Middletown, Ct., Sept.* 19, 1842.

LIST OF WORKS

Made use of, more or less, in the preparation of this work.

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Traité de Mineralogie, par M. L'Abbé Haüy. Quatre Tomes.

Eléments de Physique, etc., par M. Pouillet. Quatre Tomes.

Besides the above, reference has often been made to various other works as Le Dictionnaire des Sciences Naturelles, Annales de Chimie et de Physique, the various Encylopedias, Philosophical Transactions, &c.

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INTRODUCTION.

The science of nature, or general physics, according to the different points of view under which we contemplate natural bodies and the phenomena which they present, is divided into three great branches,—Natural History, Natural Philosophy, and Chemistry.

The first of these branches, which alone comprehends three distinct sciences, mineralogy, zoology, and botany, has for its object to describe and classify the different organic and inorganic substances.

Natural Philosophy treats of the general and permanent properties of bodies, of the laws which govern them, and the reciprocal action which these bodies are capable of exerting upon each other at greater or less distances, without changing their nature.

Chemistry includes the study of all those phenomena which depend upon an intimate action of the ultimate atoms of bodies of different kinds upon each other—an action which takes place only at infinitely small distances, and which always results in the production of bodies possessing new properties.

Chemistry may therefore be defined, the science, the object of which is to determine the action which the ultimate particles of matter exert upon each other.

We understand by the action of the ultimate atoms of matter, the effect of a cause which is unknown to us, but which tends to unite the particles of one body to those of another, or to separate these particles in order to combine them with those of other bodies either in another order or in other proportions.

This force, the cause of which is entirely unknown, but whose effects are so sensible, forms the foundation of the science of chemistry, and has been called molecular attraction, because it is exerted only among the ultimate atoms or molecules of bodies.

The name atom or molecule has been given to the smallest or ultimate particles of bodies, which are so minute that they entirely escape our senses. They are divided into two kinds, integral particles or atoms and constituent atoms.

The first are those, a collection of which forms the body tc which they belong, and all of which are like the mass from which they are taken. Thus, if we conceive a stick of sulphur reduced to a very fine powder, each small particle thus produced will be exactly like the whole mass; it is yellow, brittle, combustible, and, in a word, possesses all the properties which characterize the mass. These particles, which are always like the mass from which they were taken, are called *integrant particles.*

We give the name *constituent particles* to those which, by their union, form the integrant particles of bodies. Thus, in sulphuret of iron, a body composed of sulphur and iron, the particles of the two simple bodies, sulphur and iron, are the constituent atoms or particles of the compound; and if this sulphuret of iron be reduced to powder, each particle of the powder composed of sulphur and iron would be an integrant particle.

From these definitions it will be seen that any body never has but one kind of *integrant particles*, but that it may have many kinds of *constituent particles.* Indeed, a body must always have as many kinds of constituent particles as there are different principles entering into its composition.

The various bodies which compose the matter of our globe are divided into *simple* and *compound.*

The simple bodies, of which only fifty-five or fifty-six are known with certainty, are such as have never been decomposed or separated into more simple elements; they are therefore supposed to contain only one kind of particles.

Compound bodies are produced by the union of the particles of two or more simple bodies.

The particles of bodies, whether simple or compound, do not seem to be in actual contact, but are held in their places by two forces of attraction and repulsion acting in opposition to each other; hence the same body may occupy more space at some times than at others, that is, it may be expanded and contracted. The form which tends to bring the particles in contact is called *cohesion;* and is always exerted between particles of the same kind, and only at insensible distances, or apparent contact.

Repulsion is supposed to be occasioned solely by heat, which, by being interposed between the particles of bodies, prevents their contact. The greater the quantity of heat present, the farther will the particles of the body be removed from each other, and of course the greater will be its bulk or volume; and the colder the body is, the more nearly will they approximate.

Matter is also subject to another kind of attraction, called *chemical attraction* or *affinity.* Like cohesion it acts only at insensible distances, but, unlike that force, it is exerted between particles of different kinds. It will be seen, therefore, that affinity unites the constituent particles or atoms of bodies, while cohesion is exerted only between the integrant particles.

The separation of the constituent particles of a substance is called its decomposition.

Matter is indestructible; that is, it cannot be made to cease to exist. This statement seems at first view contrary to fact. Water and other volatile substances are dissipated by heat; and coals and wood are consumed in the fire and disappear. But in these and other similar phenomena, not a particle of matter is annihilated, but the apparent destruction is owing merely to a change of form or of composition. The power of the chemist is, therefore, limited to the production of these changes.

The composition of a body may be determined in two ways, analytically or synthetically. By analysis, the elements of a compound are separated from one another, as when water is resolved by the agency of galvanism into oxygen and hydrogen; by synthesis they are made to combine, as when oxygen and hydrogen unite by the electric spark, and generate a portion of water. Each of these kinds of proof is satisfactory; but when they are conjoined — when we first resolve a particle of water into its elements, and then reproduce it by causing them to unite—the evidence is in the highest degree conclusive.

The arrangement adopted in this work is very nearly the same as that of Dr. Turner; the most important change that has been made, consists in the transfer of the remarks on Crystalography from the chapter on Salts to that on Chemical Combinations. The reasons for the change, it is believed, will be obvious to every one acquainted with the science. The work is divided into four principal parts. The first comprehends an account of the nature and properties of *Heat*, *Light*, and *Electricity*—agents so diffusive and subtile, that the common attributes of matter cannot be perceived in them. They are altogether destitute of weight; at least, if they possess any, it cannot be discovered by our most delicate balances, and hence they have received the appellation of *Imponderables*. They cannot be confined and exhibited in a mass like ordinary bodies; they can be collected only through the intervention of other substances. Their title to be considered material is, therefore, questionable, and the effects produced by them have accordingly been attributed to certain motions or affections of common matter. It must be admitted, however, that they appear to be subject to the same powers that act on matter in general, and that some of the laws which have been determined concerning them are exactly such as might have been anticipated on the supposition of their materiality. It hence follows that we need only regard them as subtile species of matter, in order that the phenomena to which they give rise may be explained in the language, and according to the principles, which are applied to material substances in general.

The second part comprises *Inorganic Chemistry.* It includes the doctrine of affinity, the laws of combination and crystalization, together with the chemical history of all the elementary principles hitherto discovered, and of those compound bodies which are not the product of organization.

Elementary bodies are divided into the non-metallic and metallic; and the substances contained in each division are treated in the order which, it is conceived, will be most convenient for the purposes of teaching. From the important part which oxygen plays in the economy of nature, it is necessary to begin with the description of that principle; and from the tendency it has to unite with other bodies, as well as the importance of the compounds it forms with them, it will be useful, in studying the history of each elementary body, to describe the combinations into which it enters with oxygen gas, and then the compounds it forms with the other simple non-metallic elements *which have previously been described*, as far as is consistent with the design of the book.

The description of the individual metals will be accompanied by a history of their combinations, first with each other, and then with the simple non-metallic elements. The last division of this part will comprise a history of the salts.

The third general division of the work is *Organic Chemistry*, a subject which will be conveniently discussed under two heads, the one comprehending the products of vegetable, the other of animal life.

The fourth part, which will be inserted if the size of the book does not become too great, will contain brief directions for the performance of *Analyses.*

MANUAL OF CHEMISTRY.

PART I.

IMPONDERABLE SUBSTANCES.

CHAPTER I.

HEAT, OR CALORIC.

SECTION I.

DISTRIBUTION OF HEAT, OR CALORIC.

1. No sensations are more familiar than those of heat and cold. The same body is capable of producing every variety of these sensations, from intense heat to intense cold, without having its properties permanently changed; and it is hence inferred that they are not caused by the matter of the body itself, but by some other power or principle occasionally present in different quantities.

Whether heat be really a material substance, is not known; but in describing its effects, it is usual to speak of it as an exceedingly subtile fluid, the particles of which repel each other, but are attracted by all other substances.

2. The term *Heat*, however, in common language, has two meanings: in the one case, it implies the sensation experienced on touching a hot body; in the other, it expresses the cause of that sensation. When used in the latter sense, it is synonymous with the word *Caloric*, (from *Calor*, heat,) which is employed exclusively to signify the cause or agent by which all the effects of heat are produced. But in practice the distinction is not usually very rigidly observed.

3. Heat is imponderable: that is, it is so exceedingly light that a body undergoes no appreciable change of weight, either by the addition or abstraction of heat. It is present in all bodies, and cannot be wholly separated from them. For if a substance, however cold, be transferred into an atmosphere which is still colder, a thermometer placed in the body will indicate the escape of heat. That its particles repel one

another is proved by observing that it flies off from a heated body; and that it is attracted by other substances, is inferred from the tendency it has to penetrate their particles, and to be retained by them.

4. Heat may be transferred from one body to another. Thus, if a cup of mercury at 60° be plunged into hot water, heat passes rapidly from one into the other, until the temperature in both is the same; that is, till a thermometer placed in each stands at the same height. All bodies on the earth are constantly tending to attain an equality, or what is technically called, an *equilibrium*, of temperature. If, for example, a number of substances of different temperatures be enclosed in an apartment, in which there is no actual source of heat, they will soon acquire an equilibrium, so that a thermometer will stand at the same point in all of them. Our varying sensations of heat and cold are owing to a like cause. On touching a hot body, heat passes from it into the hand, and excites the feeling of warmth; when we touch a cold body, heat is communicated to it from the hand, and thus arises the sensation of cold.

5. Heat is communicated from a hot body to others which are colder in two ways, by *direct contact*, and by *radiation*. By *direct contact*, when the hot body touches a cold one, so that the heat may pass directly from one into the other, as when a bar of iron is put into a fire, or the hand plunged into hot water. By *radiation*, when the heat leaps as it were from a hot to a cold body through an appreciable interval; as when a red-hot ball suspended in the vacuum of an air-pump distributes its heat to surrounding objects, or as when we are warmed by standing at some distance before a fire. In studying these phenomena, we must regard both the loss of heat in the hot body, and the gain of heat in the cold one.

6. The mode in which a hot body cools is, firstly, by giving off heat from its surface either by contact or radiation, or both conjointly; and, secondly, by the heat in its interior passing from particle to particle through its substance to its surface. The heating of a cold body is effected, firstly, by heat passing into its surface either by contact or radiation, or by both conjointly; and, secondly, by the heat at its surface passing from particle to particle through its interior portions

7. When two bodies of different temperature are in actua contact, the principal conditions which influence the communi cation of heat from one to the other, are, the degree of conti guity and the conducting power of the substances. The more perfect the approximation, the more rapid, other things being equal, is the transfer. The contact of two solids, or a solid with a gas, is, in general, of a less perfect kind, and at fewer points, than that between a solid and a liquid; and hence, so far as contact alone is concerned, the transfer is more rapid in the

latter case than in the former. It is still more rapid when liquids are mixed with each other, or gases with gases, owing to the intermixture of their particles. When bodies touch each other at their surfaces only, the rapidity of transfer will depend upon the velocity with which caloric passes through their substances, and the question becomes one of conduction merely.

We shall therefore continue the discussion of the subject of this section, under the two heads of *conduction* and *radiation.*

CONDUCTION OF HEAT.

8. By this term is expressed the passage of heat from particle to particle, through the substance of bodies. Heat is said to be conducted by them, or to pass by *conduction*, and the property on which its transmission depends is termed their *conducting power.*

9. If on a cold morning of winter, the hand is placed successively upon a piece of metal, and then upon a piece of wood, the former will feel much colder than the latter, because the metal in equal times conveys away from the hand much more caloric than the wood. Daily experience also teaches that we cannot leave one end of a rod of iron for some time in the fire, and then touch its other extremity without danger of being burned, yet with a rod of glass, or wood, or charcoal, of but few inches in length, it may be done with safety. If a piece of metal or other substance is heated to the boiling point of water, and immediately plunged into mercury till the substance becomes of the same temperature as the mercury, and again heated as before and plunged into olive oil, it will be found to require a much longer time to cool in the latter than in the former case. By observing these and similar facts, it is very evident that different bodies conduct or transmit caloric with different degrees of velocity. All material substances are, therefore, divided into the two classes of *conductors* and *non-conductors* of heat. The former division, of course, includes those bodies, such as the metals, which allow heat to pass through them freely; and the latter comprises those which do not give an easy passage to it, such as marble, glass, wood, and charcoal. The division is, therefore, rather relative than absolute;—the non-conductors permit caloric to pass through their substances, but with less velocity than the conductors.

10. *Conduction in Solids.*—Various methods have been adopted for determining the relative conducting power of different substances. The mode devised by Ingenhouz was to cover small rods of the same form, size, and length, but of different materials, with a layer of wax, to plunge their extremities into heated oil, and note to what distance the wax was melted on each during the same interval. The metals were

found, by this method, to conduct heat better than any other substances; and of the metals, silver is the best conductor; gold comes next; then tin and copper, which are nearly equal; then platinum, iron, and lead.

Some experiments were made by Despretz, apparently with great care, on the relative conducting power of the metals and some other substances, and the results are contained in the following table:

Gold	1000	Tin	303.9
Silver	973	Lead	179.6
Copper	898.2	Marble	23.6
Platinum	381	Porcelain	12.2
Iron	374.3	Fine Clay	11.4
Zinc	363		

The substances employed for these experiments were made into prisms of the same form and size. To one extremity a constant source of heat was applied, and the passage of heat along the bar was estimated by small thermometers placed at regular distances, with their bulbs fixed in the substance of the prism. The results, as contained in the table, do not agree entirely with those of Ingenhouz, or of other experimenters, but they may without question be considered as a near approximation to the truth.

11. A convenient method to determine the relative conducting power of different substances, is, to have them made into cylinders of equal diameter, and set in a thin piece of wood at sufficient distances from each other, both extremities of each piece projecting from one to two inches from the wood. If the board be held in a horizontal position, a small piece of phosphorus may be placed upon the upper extremity of each of the substances experimented upon, and the lower ends exposed to the same temperature by plunging them in heated oil, or sand that has been previously well mixed after being heated; and the times that elapse before the ignition of the phosphorus upon the several substances, will indicate with some correctness, their relative conducting powers.

This principle will explain why a piece of paper wound closely around a cylinder of metal and held in the flame of a lamp is not even scorched for some time, though, if wood had been used instead of metal, the paper would have taken fire immediately. An experiment of this kind is sometimes performed by holding a handkerchief closely in contact with the back of a silver watch, and touching it with ignited charcoal. It is said the handkerchief cannot be burned in this way; but it would be more correct to say, it cannot be done without difficulty.

12. An ingenious plan was adopted by Count Rumford for ascertaining the relative conducting power of the different materials employed for clothing He enveloped a thermometer in a glass cylinder blown into a ball at its extremity, and filled the interstices with the substance to be examined. Having heated the apparatus to the same temperature in every instance by immersion in boiling water, he transferred it into melting ice, and observed carefully the number of seconds which elapsed during the passage of the

thermometer through 135 degrees. When there was air between the thermometer and cylinder, the cooling took place in 576 seconds; when the interstices were filled with fine lint, it took place in 1032″; with cotton, in 1046″; with sheep's wool, in 1118″; with raw silk, in 1284″; with beaver's fur, in 1296″; with eider down, in 1305″; and with hare's fur, in 1315″.

13. Many efforts have been made to determine the cause of this great difference in the conducting power of different bodies, but hitherto with little avail. The conducting power of solid bodies does not seem to be related to any of the other properties of matter; but it approaches nearer to the ratio of their densities than that of any other property. Count Rumford found a considerable difference in the conducting power even of the same material, according to the state in which it was employed. His observations seem to warrant the conclusion, that, in the same substance, the conducting power increases with the compactness of structure.

14. The metals, as already remarked, are much the best conductors of caloric known, while glass, pottery, clay, resin, charcoal, feathers, silk, wool, &c., are generally considered non-conductors.

The non-conducting power of cotton, wool, fur, and other similar substances, is supposed to be occasioned by the air mechanically held among their fibres.

15. Advantage is taken of the imperfect conducting powers of bodies, to prevent the passage of heat in any direction, particularly in confining it. Hence furnaces are generally lined with "fire-brick," or a thick coating of clay and sand. Wooden handles are fitted to metallic vessels, or a stratum of wood or ivory is interposed between the hot vessel and the metal handle. Double windows, as in Kensington Palace, England, and double doors, with an interposed stratum of air, are sometimes used. Ice-houses are often constructed with double walls which have their interstices filled with fine charcoal, or some other non-conducting substance, to prevent the influx of heat from without.

16. The design of clothing is to retain the heat produced by the system; and hence the warmest clothing will be that which possesses the least conducting power. By reference to the experiments of Count Rumford, mentioned above, it will be seen that the general practice of mankind, in their selection of clothing, is fully justified by experiment. In winter the poorest conductors are selected, and in summer the best, as it is then desirable that the superfluous heat may be permitted at once to escape. If, in summer, the temperature of the atmosphere should rise considerably above that of the system, it would be found advantageous to use the same clothing as in cold weather, in order to prevent the accession of heat from without.

17. Snow, in consequence of its imperfect conducting power, serves as clothing to the earth in winter, and prevents its surface from being cooled down as low as it would otherwise be.

On the other hand, advantage is taken of the conducting power of bodies in extending large cylinders or prisms of metal from the fire in kitchen-ranges to ovens at a little distance, which, by the caloric conducted along the metal, are kept constantly at the proper temperature. Cylinders of metal are sometimes made to extend from the centre of the oil vessels of lamps used in light-houses, and terminate in knobs directly over the tops of the glass chimneys surrounding the wicks. A portion of the heat produced by the lamp is thus conveyed to the oil to prevent it from congealing.

18. *Conduction in Liquids.*—Liquids may be said, in one sense of the word, to have the power of conveying heat with great rapidity, though in reality they are very imperfect conductors. This peculiarity is owing to the mobility which subsists among the particles of all fluids, and the change of size which is always produced by a change of temperature. When any particles of a liquid are heated they expand, thereby becoming specifically lighter than those which have not received an increase of temperature; and if the former happen to be covered by a stratum of the latter, these from their greater density will descend, while the warmer and lighter particles will be pressed upwards. It therefore follows that, if heat enter at the bottom of a vessel containing a liquid, a double set of currents must be immediately established, the one of hot particles rising towards the surface, and the other of colder particles descending to the bottom. Now these currents take place with such rapidity, that if a thermometer be placed at the bottom, and another at the top of a long jar, the fire being applied below, the upper one will begin to rise almost as soon as the lower. The transportation of hot particles by this process has been termed the *convection* of heat.

19. But if, instead of heating the bottom of the jar, the heat enter by the upper surface, very different phenomena will be observed. The intestine movement cannot then be formed, because the heated particles, from being lighter than those below them, remain constantly at the top; the heat can descend through the fluid only by transmission from particle to particle, a process which takes place so very tardily, as to have induced Count Rumford to deny that water can conduct at all. In this, however, he was mistaken; for the opposite opinion has been successfully supported by Hope, Thomson, and Murray, though they all admit that water, and liquids in general, mercury excepted, possess the power of conducting heat in a very slight degree.

20. The establishment of the upward and downward currents, when heat is applied to the bottom of the vessel containing a fluid, may be shown by putting some pieces of amber or gum copal into a vessel of water, and placing it over a small spirit-lamp. The piece of amber or gum will be seen to rise vertically in the centre, and, on reaching the surface, move towards the sides of the vessel which are colder, from the influence of the external air; they then sink and rise again as before.

When the boiling point is nearly attained, the particles being nearly of the same temperature, the circulation is retarded. The portions in contact with the heated surface are converted into steam before they can be succeeded by others; but the steam thus produced cannot rise far before it is condensed. Hence the vibration and singing observed at this time.—*Dr. Hare.*

21. The extremely poor conducting power of water may be shown by cementing a thermometer in a glass funnel, which is to be inverted and filled with water so as to cover the bulb of the thermometer about a quarter of an inch. If now a little ether be gently poured upon the water, it may be inflamed without producing any sensible effect upon the thermometer.

When large quantities of water are slowly heated, the upper portions will frequently be found quite warm, while that in the lower part of the vessel will remain comparatively cold; and this though the fire is applied beneath. Hence it is not unfrequent, in bathing establishments, to draw both warm and cold water from the same reservoir.

22. If a tube ten or twelve inches long be nearly filled with water and placed in an inclined position, so that the heat of a spirit-lamp can be applied near the centre, the water in the upper part of the tube may be made to boil, while the lower portion will remain as cold, or nearly so, as at first. If, at the commencement of the experiment, the temperature of the water be near the freezing point, and a piece of ice be confined at the bottom, it will remain long after the water boils above it, before it will be melted.

23. *Conduction in Gases.*—It is extremely difficult to estimate the conducting power of aeriform fluids. Their particles move so freely on each other, that the moment a particle is dilated by heat, it is pressed upwards with great velocity by the descent of colder and heavier particles, so that an ascending and descending current is instantly established. Besides, these bodies allow a passage through them by radiation. Now the quantity of heat which passes by these two channels is so much greater than that which is conducted from particle to particle, that we possess no means of determining their proportion. It is certain, however, that the conducting power of gaseous fluids is exceedingly imperfect, probably even more so than that of liquids.

RADIATION.

24. When the hand is placed beneath a hot body suspended in the air, a distinct sensation of warmth is perceived, though from a considerable distance. This effect does not arise from the heat being conveyed by means of a hot current; since all the heated particles have a uniform tendency to rise. Neither, for reasons above assigned, can it depend on the conducting power of the air; because aerial substances possess this power in a very low degree, while the sensation in the present case is

excited almost on the instant. There is, therefore, another mode by which heat passes from one body to another; and as it takes place in all gases, and even *in vacuo*, it is inferred that the presence of a medium is not necessary to its passage. This mode of distribution is called *radiation* of heat, and the heat so distributed is called *radiant*, or *radiated heat*. It appears, therefore, that a heated body suspended in the air cools, or is reduced to an equilibrium with surrounding bodies, in three ways; first, by the conducting power of the air, the influence of which is very trifling; secondly, by the mobility of the air in contact with it; and thirdly, by radiation.

25. *Laws of Distribution.*—Heat is emitted from the surface of a hot body equally in all directions, and in right lines, like radii drawn from the centre to the surface of a sphere; so that a thermometer placed at the same distance on any side would stand at the same point, if the effect of the ascending current of hot air could be averted. The calorific rays, thus distributed, pass freely through a vacuum, and the air, without being arrested by the latter, or in any way affecting its temperature. When they fall upon the surface of a solid or liquid substance, they may be disposed of in three different ways:—1, they may rebound from its surface, or be *reflected;* 2, they may be received into its substance, or be *absorbed;* and 3, they may pass directly through it, or be *transmitted.* In the first and third cases, the temperature of the body on which the rays fall is altogether unaffected; whereas, in the second it is increased. The heating influence varies with the distance from the radiating body. The rate or law of decrease, as ascertained by careful experiment, and as may be inferred from mathematical considerations, is, that the intensity of heat diminishes in the same ratio as the squares of the distances from the radiating point increase. Thus the thermometer will indicate four times less heat at two inches, nine times less at three inches, and sixteen times less at four inches, than it did when it was only one inch from the heated substance.

26. The radiation of heat from hot bodies is singularly influenced by the nature and condition of their surfaces, a circumstance which was first illustrated by Leslie, in his Essay on Heat, published in 1804. In his experiments he used a cubical vessel of tin filled with hot water as the radiating substance; and the calorific rays proceeding from it were brought to a focus by means of a concave mirror, and their intensity ascertained by a differential thermometer. By adapting thin plates of the metals to the different faces of the cubical vessel, or coating them with other substances, and bringing them opposite the mirror, the following results were obtained. 1. Bright and polished metallic surfaces radiate caloric very imperfectly. 2. The radiating power is much increased, simply by scratching the surface, or rendering it in any way rough or dull, as by

coating it with wax, whiting, or lampblack. 3. The radiating power of the different metals is nearly equal, provided they are susceptible of equal polish. 4. The power of a body to radiate caloric does not depend entirely upon the condition of its surface, since a highly polished piece of glass radiates far better than an equally polished metallic surface.

27. The different radiating power of different surfaces may be shown by taking two cylindrical vessels, capable of holding about a half-pint each, with an orifice at the top like a common vial that may be closed with a cork. If now one of the vessels be coated with lampblack or powdered chalk, and both filled with boiling water, after standing a short time, a thermometer inserted into the vessels successively will show that the contents of the coated vessel are approaching the temperature of the atmosphere much more rapidly than those of the other. After a certain interval, the finger may be immersed in the water of the coated vessel without danger, while that in the other remains at a scalding temperature. If the surface of one of the vessels is made rough by scratching it with sand-paper, a similar effect will be observed. In both cases the quantity of caloric contained in the vessels was equal, but one vessel permitted it to escape by radiation more rapidly than the other.

28. Lampblack has been found to form the best radiating surface of any known substances. If its radiating power be estimated at 100, that of glass, it is said, will be 90, bright lead 19, and tin plate only 12; and though bright lead radiates with a power of but 19, if it be a little tarnished, its power is raised to 45.

29. In general it may be affirmed that all substances in nature have different radiating powers. In the case of the metals, the radiation appears to depend merely upon the surface, without reference to the thickness; but in case of other radiating substances, something depends upon the thickness of the coating constituting the surface, the increase of which within moderate limits increases the radiation. If a very thick coating be applied, the result will of course depend in part upon the conducting power of the substance, as well as the nature of the surface.

30. By some recent experiments, (Phil. Trans. 1833, Part II,) it appears to be satisfactorily determined that, other things being equal, dark-colored surfaces radiate caloric more freely than lighter-colored ones.*

31. Several important suggestions will naturally arise from a review of the preceding doctrines. Whenever it is desired that the heat of a fluid or other substance should be retained, vessels with bright and polished metallic surfaces should be used, but the reverse if the heat is to be distributed. Thus tea and coffee-pots are usually made of some bright metal,

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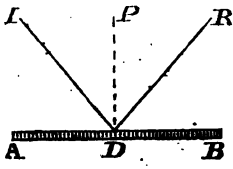
*This opinion has been controverted by Professor A. D. Bache, with much plausibility. Farther experiments are needed.—*Sil. Jour.*, xxx., 16.

while stoves and stove-pipes, for the diffusion of heat, are made with dark and rough surfaces. Pipes to convey steam from the boilers in steam-engines to the cylinders, and pipes to convey heated air from furnaces to the different apartments of a building, should be bright, or else they should be protected by some non-conducting covering.

32. *Reflection of Heat.*—That heat may be reflected may be shown by standing at the side of a fire in such a position that the heat cannot reach the face directly, and then placing a plate of tinned iron opposite the grate, and at such an inclination as permits the observer to see in it the reflection of the fire; as soon as it is brought to this inclination, a distinct impression of heat will be perceived upon the face.

33. If a line be drawn from a radiating substance to the point of a plane surface by which its rays are reflected, and a second line from that point to the spot where its heating power is exerted, the angles which these lines form with a line perpendicular to the reflecting plane are called the angles of *incidence* and *reflection*, and are invariably equal to each other.

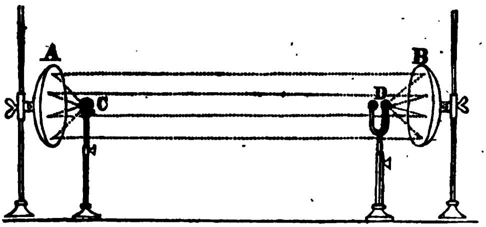
Fig. 1.



34. Thus let AB, figure 1, be the reflecting surface, and R a ray of heat which strikes this surface at D in the direction RD; it will be thrown off or reflected in the direction DI. If a perpendicular PD be erected at the point D, the angle RDP will be the angle of incidence, and IDP the angle of reflection.

It follows, from this law, that when a heated body is placed in the focus of a concave parabolic reflector, the diverging rays which strike upon it assume a parallel direction with respect to each other; and that when these parallel rays impinge upon a second concave reflector standing opposite to the former, they are made to converge so as to meet together in its focus. Their united influence is thus brought to bear upon a single point.

Fig. 2.



35. The manner of performing the experiment will be seen by inspecting figure 2. A and B are two concave parabolic mirrors. If a heated ball C is placed in the focus of one of them, A, the rays of heat striking its surface will be reflected in parallel lines to the second mirror, B, and be again col

lected, by a second reflection, in its focus, D; as will at once be shown by a thermometer placed there.

36. It has been known for ages that the heat contained in the solar rays admits of being reflected by mirrors, and a like property has long since been recognised in the rays emitted by red-hot bodies; but that heat emanates in invisible rays, which are subject to the same laws of reflection as those that are accompanied by light, is a modern discovery, noticed indeed by Lambert, but first decisively established by Saussure and Pictet of Geneva. They first proved it of an iron ball, so heated as not to be luminous even in the dark, and then of a vessel of boiling water; but for most of our knowledge of this subject we must again refer to the labors of Leslie. He demonstrated that the reflecting power depends on the nature and condition of surfaces; and that those qualities which are adverse to radiation are precisely such as promote reflection. Bright smooth metallic surfaces, as polished silver, brass, or tin, which are retentive of their own heat, are little prone to receive heat from other sources, but cause such rays to fly off from them; while those qualities of a surface which facilitate radiation from a hot body, likewise unfit it for reflecting the rays which fall upon it from surrounding objects. His experiments, indeed, justify the conclusion that the faculty of radiation is inversely as that of reflection.

37. *Absorption of Heat.*—Every increase of temperature arising from radiant heat is due to its absorption or reception into the body on which it falls. If a pencil of heat impinges upon the surface of a body through which no portion of it is transmitted, it must, as a matter of course, either be reflected or absorbed: those rays which are reflected cannot be absorbed; and those which are not reflected must be absorbed. The number of absorbed rays is supplemental to that of the reflected rays. It hence follows that as the reflecting power is materially influenced by the nature of surfaces, the absorptive power must be so likewise. Those qualities of a surface which increase reflection are to the same extent adverse to absorption; and those which favor absorption are proportionally injurious to reflection. Since, moreover, as has just been shown (36), the property of radiation is inversely as that of reflection, the power of radiating is directly proportional to that of absorbing heat.

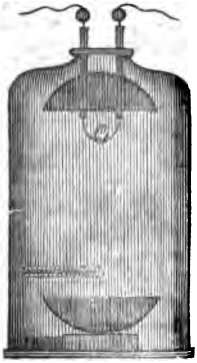
38. Surfaces may therefore be divided into two classes, those which afford an easy passage to heat, and those which do not. The former will be good radiators and absorbers, and the latter good reflectors and retainers.

39. The *color* of surfaces influences the absorption of radiant heat. This has been observed by several persons of the sun's rays, and of terrestrial heat associated with light, as will be stated hereafter; but the depend

ence of the absorptive power for simple heat on color has not till lately been noticed. From researches by Dr. Stark it seems that differently colored wools wound upon the bulb of a thermometer, and exposed within a glass tube to hot water, rose from 50° to 170° in the following times,—black wool in 4′ 30″, dark green in 5′, scarlet in 5′ 30″, white in 8′.

40. An interesting connection has been traced by Nobili and Melloni between the absorbing and conducting power of surfaces, in some able researches, which, if free from fallacy, justify the inference that the radiating and absorbing powers of surfaces for simple heat are in the inverse order of their conducting power.

Fig. 3.



41. *Transmission of Heat.*—Radiant heat passes with perfect freedom through a vacuum. The air and gaseous substances present a considerable barrier to its progress. An experiment of Davy seems conclusive as to this point. He contrived to heat a platinum wire by means of galvanism within a receiver containing two concave reflectors, with a thermometer in the focus of one of them, the heated wire being in the focus of the other. Now when the air was exhausted to $\frac{1}{120}$th part of its ordinary density, the thermometer, it was found, would be raised by means of the ignited wire, three times as high as when the air in the receiver was at its natural pressure.

42. Most transparent media of a denser kind, such as the diamond, rock-crystal, glass, and water, even in thin strata, greatly interfere with its passage; and when in moderately thick masses, intercept it altogether. This last remark, however, is applicable only to *simple-radiant heat*, that is, to heat unaccompanied with light. The solar rays pass readily through glass, both heat and light being refracted in their passage, as is shown by the common burning-glass; and though much of the heat emitted by the flame of a lamp, or a red-hot iron ball, is arrested by glass, many of the calorific rays are directly transmitted with the light. But the result is different when the heated body is not luminous. A thin screen of glass, interposed between such an object and a thermometer, certainly intercepts most of the rays that fall upon it; and the sole question which can be raised is, whether the small effect on the thermometer is caused by direct transmission, or by the screen first becoming warm by the absorption of the rays, and then acting on the thermometer by radiation. On this point there was long much difference of opinion, but the question has at length been put at rest by the able research of Melloni, made with a thermomultiplier, an instrument which is capable of indicating extremely slight changes of temperature. He has

proved that substances differ in their power to transmit the rays of heat just as they differ in their action upon those of light. Some allow the rays of heat to pass through them readily and are called *transcalent* or *diathermanous*, while others entirely intercept them, and are called *intranscalent* or *adiathermanous*. Several of the important conclusions established by him are as follows, viz.:

1. Transcalent bodies are generally more or less transparent, but some, as black glass and black mica, are opake. The transparency and transcalency of a substance, however, are not usually in the same proportion.

2. Transcalent bodies differ very much in their power to transmit the calorific rays; and in glass and liquids those are generally most transcalent which refract light most powerfully.

Rock-salt appears to transmit all the rays of heat; and this is the only substance yet known which is perfectly diathermanous.

3. The proportion of heat transmitted through glass and other diathermanous substances, varies with the temperature of the source from which the rays emanate. The higher the temperature the greater is the proportion transmitted, except in the case of rock-salt, which is equally permeable to rays of a high or low temperature.

The rays of heat like those of light may be refracted; and some of them being more refrangible than others, like the different colors of light, they may be separated from each other by means of the prism.—See *Decomposition of Light.*

It has also been ascertained that heat may undergo *double-refraction* and *polarization*, in the same manner as light.

43. *Theory of Radiation.*—It is well known that several bodies, differently heated, placed in the vicinity of each other, and at a distance from any source of heat, will gradually assume the same temperature. Two theories have been proposed to account for this transfer of caloric from the warmer to the colder body—one by Pictet, and the other by Prevost of Geneva. Pictet's theory supposes that bodies of equal temperature do not radiate any caloric; but when the bodies are of unequal temperature, the warmer give calorific rays to the colder, until an equilibrium is established, when the radiation ceases.

But the theory of Prevost is the one generally adopted. This supposes that all bodies at every temperature are constantly radiating caloric to surrounding objects, and, of course, receiving caloric from them in return. Consistently with this view, the temperature of a body falls whenever it radiates more heat than it receives; its temperature is stationary when the quantities emitted and received are equal; and it becomes warmer when it receives more than it radiates. A hot body, surrounded by others colder than itself, affords an instance of the first case; the second happens when all the substances within the sphere of each other's radiation are of the same temperature; and the third occurs when a body is introduced into a room that is warmer than itself.

44. An argument in favor of this theory is drawn from the close analogy which is observed between the laws of heat and light. Luminous bodies of different intensity certainly exchange rays with one another, and the same is inferred to be true with regard to the calorific rays.

Indeed, there appears to be no point of temperature at which caloric is not given out by bodies. Even ice, which feels so cold to the touch, becomes a source of heat in a chamber where the temperature of the air is at zero, and a body at zero would radiate caloric in an atmosphere at 40° below zero.

This theory admirably explains all the ordinary phenomena of radiation, but it has been supposed to fail in some few cases, particularly in an experiment originally performed by the Florentine Academicians, and since carefully repeated with the same results by others. A ball of ice was placed in the focus of a concave mirror, which occasioned a thermometer placed in the focus of another similar mirror standing opposite to it (35) to fall several degrees. At first it was supposed that rays of cold were actually emitted by the ice, but by a little examination it will be seen that the phenomenon is a necessary consequence of Prevost's theory; as in this case the thermometer itself becomes the heated body, from which heat is given off to the ice.

45. *Formation of Dew.*—An elegant application of this theory was made by Wells to account for the formation of dew. The most copious deposit of dew takes place when the weather is clear and serene; and the substances that are covered with it are always colder than the contiguous strata of air, or than those bodies on which dew is not deposited. In fact, dew is a deposition of water previously existing in the air as vapor, and which loses its gaseous form only in consequence of being chilled by contact with colder bodies. In speculating, therefore, about the cause of this phenomenon, the chief object is to discover the cause of the reduction of temperature. The explanation proposed by Wells, in his excellent Treatise on Dew, and now almost universally adopted, is founded on the theory of Prevost. If it be admitted that bodies radiate at all times, their temperature can remain stationary only by their receiving from surrounding objects as many rays as they emit: and should a substance be so situated that its own radiation may continue uninterruptedly without an equivalent being returned to it, its temperature must necessarily fall. Such is believed to be the condition of the ground in a calm starlight evening. The calorific rays which are then emitted by substances on the surface of the earth are dispersed through free space and lost: nothing is present in the atmosphere to exchange rays with them, and their temperature consequently diminishes. If, on the contrary, the weather be cloudy, the radiant heat proceeding from the earth is intercepted by the

clouds, an interchange is established, and the ground retains nearly, if not quite, the same temperature as the adjacent portions of air.

46. All the facts hitherto observed concerning the formation of dew tend to confirm this explanation. Dew is deposited sparingly or not at all in cloudy weather; all circumstances which promote free radiation are favorable to its deposition; good radiators of heat, such as grass, wood, the leaves of plants, the filamentous substances in general, reduce their temperature, in favorable states of the weather, to an extent of ten, twelve, or even fifteen degrees below that of the circumambient air: and, while these are drenched with dew, pieces of polished metal, smooth stones, and other imperfect radiators, are barely moistened, and are nearly as warm as the air in their vicinity.

47. Wells has also shown that the formation of artificial ice in some parts of India depends upon the radiation of heat from the surface of the water. The nights which answer best for making this ice are clear and calm. The water is put in shallow pans, which are so placed that the heat from the ground cannot readily penetrate them. The congelation is usually greatest just before sunrise; and as dew is copiously deposited, it is obvious that no evaporation can take place from its surface. Formerly it was supposed that the cold was produced by the evaporation from the surface, an explanation which it seems must be given up as fallacious.

48. The temperature at which dew begins to be deposited is called the *dew-point*, which, even when the air is saturated with moisture, will obviously be below the temperature of the atmosphere. In summer this point is usually considerably above the temperature of ordinary spring-water, as is shown by the copious deposition of moisture upon the external surface of vessels containing water recently drawn from the well.

SECTION II.

EFFECTS OF HEAT.

49. The phenomena that may be ascribed to this agent, and which may therefore be enumerated as its effects, are numerous. Omitting, however, at present, any remarks concerning its influence upon animal or vegetable substances, it produces many important effects upon inorganic bodies.

50. The dimensions of every kind of matter are regulated by

this principle. Its increase, with few exceptions, separates the particles of bodies to a greater distance from each other, producing expansion, so that the same quantity of matter is thus made to occupy a larger space; and the diminution of heat has an opposite effect. Were the repulsion occasioned by this agent to cease entirely, the atoms of bodies would come into actual contact.

51. The form of bodies is dependent on heat. By its increase, solids are converted into liquids, and liquids are dissipated in vapor; by its decrease, vapors are condensed into liquids, and these become solid. If matter ceased to be under the influence of heat, all liquids, vapors, and, doubtless even gases, would become permanently solid; and all motion on the surface of the earth would be arrested.

52. When heat is accumulated to a certain extent in bodies, they shine, or become *incandescent.* On this important property depends all our methods of artificial illumination.

53. Heat exerts a powerful influence over chemical phenomena. There is, indeed, scarcely any chemical action which is not in some degree modified by this principle; and hence a knowledge of its laws is indispensable to the chemist. By its means bodies previously separate are made to combine, and the elements of compounds are disunited. An undue proportion of it is destructive to all organic and many mineral compounds; and it is essentially concerned in combustion, a process so necessary to the wants and comforts of man.

Of the various effects of heat above enumerated, several will be discussed in other parts of the work. In this place it is proposed to treat only of its influence over the dimensions and form of bodies, a subject which will be conveniently studied under the three heads of *expansion*, *liquefaction*, and *vaporization.*

EXPANSION.

54. One of the most remarkable properties of heat is the repulsion which exists among its particles, a property which enables it, on entering into a body, to remove the integrant molecules of the substance to a greater distance from each other. The body, therefore, becomes less compact than before; occupies a greater space, or, in other words, expands. This effect of heat is opposed to cohesion—that force which tends to make the particles of matter approximate, and which must be overcome before any expansion can ensue. Heat, therefore, should produce the greatest expansion in those bodies which are least influenced by cohesion, an inference fully justified by observation. Thus the force of cohesion is greatest in solids, less in liquids, and least of all in aeriform substances; while

the expansion of solids is trifling, that of liquids much more considerable, and that of elastic fluids far greater.

55. It may be laid down as a rule, the reason of which will now be obvious, that all bodies are expanded by heat, and the expansion of the same body increases with the quantity of heat which enters it. That these remarks may apply, however, it is always to be understood that the form and chemical constitution of the body are preserved. If a change in respect to either of these be occasioned, then expansion may or may not take place, not as a direct effect of augmented temperature, but as the result of the change in form or composition.

56. In proof of the expansion of solids, we need only take the exact dimensions, in length, breadth, and thickness, of any substance when cold, and measure it again while strongly heated, when it will be found to have increased in every direction. A familiar demonstration of the fact may be afforded by adapting a ring to an iron rod, the former being just large enough to permit the latter to pass through it while cold. The rod is next heated, and will then no longer pass through the ring. This dilatation from heat and consequent contraction in cooling takes place with a force which appears to be irresistible.

57. The expansion of solids has engaged the attention of several experimenters, whose efforts have been chiefly directed towards ascertaining the exact quantity by which different substances are lengthened by a given increase of heat, and determining whether or not their expansions are equable at different temperatures.

58. For low temperatures it has been satisfactorily determined that the expansion of the more infusible solids is very uniform; they increase as much, for instance, when heated from 32° to 122°, as when heated from 122° to 212°, but above this last temperature the rate of expansion increases. Indeed, from 32° to 122° they probably expand in an increasing ratio, but the differences are so small as to escape observation. Different solids do not expand equally when equally heated; but when their temperature has been raised from 32° to 212°, and allowed to fall again to 32°, they all recover precisely their original volume.

The following table exhibits the elongation of several substances when heated from 32° to 212°.

Substances tried.	*Dilatation in vulgar fraction of its own length.*	*Substances tried.*	*Dilatation in vulgar fraction of its own length.*
Flint-glass, Eng.	$\frac{1}{1248}$	Lead	$\frac{1}{351}$
Copper	$\frac{1}{581}$	Tin	$\frac{1}{517}$
Hard steel	$\frac{1}{927}$	Silver	$\frac{1}{524}$
Iron-wire	$\frac{1}{812}$	Gold	$\frac{1}{682}$
Brass	$\frac{1}{532}$	Platinum	$\frac{1}{1166}$

59. Knowing the elongation of any substance for a given number of degrees of the thermometer, its total increase in bulk may, in general, be calculated by trebling the number which expresses its increase in length. Thus, if a tube of flint-glass is elongated $\frac{1}{1248}$th, when heated from the freezing to the boiling point of water, its cubic space will be increased $\frac{3}{1248}$ or $\frac{1}{416}$ of its former capacity, It is scarcely necessary to remark that this rule is not strictly accurate, but when the expansion of any substance corresponding to the observed increase of temperature is a minute fraction of its volume, the error in practice will be altogether insensible.

60. This property of bodies, and particularly of the metals, has been applied to various useful purposes in the arts. The iron band or *tire* of a carriage-wheel is made a little smaller than the circumference of the wheel, but, being expanded, is sufficiently enlarged to be slipped on; and the immediate application of water prevents it from burning the wood, and brings the iron to its original dimensions, causing it to grasp the wheel with great firmness. Other examples will suggest themselves to the mind of the student.

61. The expansions and contractions of bodies by change of temperature also occasion some inconveniences. The accurate movement of clocks depends upon the length of their pendulums, which being sensibly affected by changes of temperature, they are made to go faster in cold, and slower in warm weather.

62. Brittle substances, when unequally heated, are often broken by the unequal expansions and contractions to which they are liable. The danger is greater if the substance is a bad conductor of heat, as is the case with glass, and particularly if it is thick. Hence, glass vessels that are to be used about the fire, or with hot water, should be made as thin as is consistent with the requisite strength.

Metallic or other instruments used for measuring length or capacity vary with change of temperature—a circumstance that sometimes occasions serious difficulty where very great accuracy of measurement is required.

63. The expansion of liquids is readily shown by putting a common thermometer, made with mercury or alcohol, into warm water, when the dilatation of the liquid will be shown by its ascent in the stem. The experiment is, indeed, illustrative of two other facts. It proves, first, that the dilatation increases with the temperature; for if the thermometer be plunged into several portions of water heated to different degrees, the ascent will be greatest in the hottest water, and least in the coolest portions. It demonstrates, secondly, that liquids expand more than solids. The glass bulb of the thermometer is itself expanded by the hot water, and, therefore, is enabled to contain more mercury than before; but the mercury, being dilated to a much greater extent, not only occupies the additional space

in the bulb, but likewise rises in the stem. Its ascent marks the difference between its own dilatation and that of the glass, and is only the apparent, not the actual expansion of the liquid.

64. Different liquids do not expand to the same degree from an equal increase of temperature. Ether expands more than alcohol, alcohol more than water, and water more than mercury. It is found by experiment that 1000 cubic inches of water at 32° when heated to 212° become 1046; but 1000 cubic inches of mercury, by an equal elevation of temperature, expand only to 1018 cubic inches.

All experimenters agree that liquids expand in an increasing ratio, or that equal increments of heat cause a greater dilatation at high than at low temperatures. Thus, if a liquid is heated from 32° to 122°, it will not expand so much as it would by being heated from 122° to 212°, though an equal number of degrees is added in both cases. In mercury the first expansion is to the second as 14 to 15; in water as 4.7 to 15.

65. There is a peculiarity in the effect of heat upon the bulk of some liquids; namely, that at a certain temperature increase of heat causes them to contract, and its diminution makes them expand. But this singular exception to the general effect of heat, is observable in those only which acquire an increase of bulk in passing from the liquid to the solid state, and is remarked only within a few degrees of temperature above their point of congelation. Water is a noted example of it. Ice, except in the case of *anchor* or *ground* ice, always swims upon the surface of water, a circumstance which affords convincing proof that in freezing it must expand. The specific gravity of ice is about 0.92; so that water in freezing must expand about 1-11th of its volume.

This expansion takes place with an enormous force, the amount of which, however, has not been determined.

66. But it is not merely during the act of congelation that water expands, for it begins to dilate considerably before it actually freezes. Dr. Croune noticed this phenomenon so early as the year 1683, and it has since been observed by various philosophers. It may be rendered obvious to any one by the following experiment. Fill a flask, capable of holding three or four ounces, with water at the temperature of 60°, and adapt to it a cork, through which passes a glass tube open at both ends, about the eighth of an inch wide and ten inches long After having filled the flask, insert the cork and tube, and pour a little water into the latter till the liquid rises to the middle of it. On immersing the flask into a mixture of pounded ice and salt, the water will fall in the tube, marking contraction; but in a short time an opposite movement will be perceived, indicating dilatation, though the water within the flask is at the same time yielding heat to the freezing mixture in which it is immersed.

67. To the inference deduced from this experiment, it has been objected that the ascent of the water in the tube does not arise from any expansion in the liquid itself, but from a contraction of the flask, by which its capacity is diminished. In fact, this cause does operate to a certain extent, but it is by no means sufficient to account for the whole effect; and, accordingly, it has been proved by an elegant and decisive experiment of Hope, that water does really expand previous to congelation. He believes the greatest density of water to be between 39.5° and 40°; that is, boiling water obeys the usual law till it has cooled to the temperature of about 40°, after which the abstraction of heat produces increase instead of diminution of volume. According to Johnston, (*Report on Chemistry to the British Association*, 1836,) the greatest density of water is at 39.24°.

68. The cause of the expansion of water at the moment of freezing is attributed to a new and peculiar arrangement of its particles. Ice is in reality crystalized water, and during its formation the particles arrange themselves in ranks and lines, which cross each other at angles of 60° and 120°, and consequently occupy more space than when liquid. This may be seen by examining the surface of water while freezing in a saucer. No very satisfactory reason can be assigned for the expansion which takes place previous to congelation. It is supposed, indeed, that the water begins to arrange itself in the order it will assume in the solid state before actually laying aside the liquid form; and this explanation is generally admitted, not so much because it has been proved to be true, but because no better one has been offered.

69. This explanation appears very plausible, especially when viewed in connection with another theory which, however, it is believed, has never been published. It is well known that, in certain situations, a kind of ice called *anchor or ground ice* forms at the *bottom* of bodies of water, instead of the surface, as is always the case with common ice. This ice possesses little if any tenacity, and, it is said, appears to consist entirely of minute crystals, which have been supposed to be the primary crystals of water. Separately, they are supposed to possess a higher specific gravity than water, but, when aggregated according to the law stated above, at angles of 60° and 120° to form common ice, on account of the interstices necessarily left among them, the volume is so increased as to diminish the specific gravity to the point we usually witness.—(*Manuscript Notes of Professor Cleaveland's Lectures in Bowdoin College, in the year* 1832.)

70. There are other facts bearing on this question. An alloy called Rose's fusible metal, formed by melting together 2 parts of bismuth, 1 of lead, and 1 of tin, fuses at about 200°, but its point of greatest density is at 155¼°. When heated above 32° it expands till the temperature rises to 110¾°; it then begins again to contract till heated to the point of greatest density above mentioned. These facts might seem to require some different explanation, but it is known that even in the solid state the particles of bodies sometimes undergo a great change in their crystaline arrangement.

Several other substances expand when they pass from the liquid to the solid state, among which cast-iron, bismuth, and antimony are usually mentioned. Mercury is a remarkable instance of the reverse; for when it freezes it suffers great contraction. The salts also expand as they crystalize.

71. The most important effects result from this remarkable property of water which has just been described. If the density of water continued to increase until it arrived at the freezing point, as is the case with mercury and other liquids, ice would be heavier than water, and as soon as formed would subside to the bottom in successive flakes, until the whole of the water, however deep, would become solid. The effects of such an arrangement can be easily conceived. Countries, which, in the present state of things, are the delightful abodes of innumerable animated beings, would be rendered uninhabitable, and must inevitably become dreary and desolate wastes. But, since water expands previously to its freezing, as well as during this change, ice is lighter than water, and floats upon its surface, protecting the water from the further influence of frost.

72. As the particles of air and aeriform substances are not held together by cohesion, it follows that increase of temperature must occasion in them considerable dilatation; and, accordingly, they are found to dilate by a given addition of heat much more than solids or liquids; and further, that the expansions for equal increments of caloric are uniform at every temperature. It has been fully established by the investigation of several philosophers, that every gas, in a perfectly dry state, expands about $\frac{1}{480}$ of its volume at 32° for every degree it is heated above this point. Hence, 100 parts in being heated from 32° to 212° will become 137.5 parts. This point being established, the mathematician will easily determine, by a simple arithmetical operation, the volume any given quantity of gas should occupy, at any given temperature.

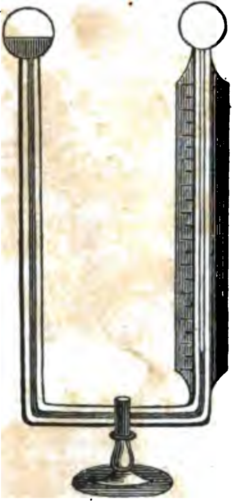
The most important effects result from the expansions and contractions of atmospheric air, by changes of temperature. To these changes we are indebted for the currents in the air which constitute winds; for the ventilation of our rooms, and for the ascending currents in chimneys and stoves.

73. *Thermometers.*—The idea of measuring the intensity of heat seems first to have been entertained by Sanctorio, a professor of philosophy of Padua, Italy, early in the seventeenth century. To accomplish this object he made use of the expansive effect of heat upon atmospheric air; and the thermometer, or *thermoscope*, (as it was then called,) which he constructed, consisted simply of a glass tube with a bulb blown at one extremity, and inverted in a vessel of colored water or other liquid. By applying a slight heat to the bulb, a portion of the air was forced out; and when it returned to its original temperature the liquid of course rose and filled a part of the tube. In this state it would indicate changes of temperature in the atmosphere with great delicacy, the alternate expansion

and contraction of the confined air being rendered visible by the corresponding descent and ascent of the colored liquid in the tube.

74. The material used in its construction also, is peculiarly appropriate; because air, like all gases, expands uniformly by equal increments of heat. There are, however, two forcible objections to the general employment of this thermometer. In the first place, its dilatations and contractions are so great that it is inconvenient to measure them when the change of temperature is considerable; and, secondly, its movements are influenced by pressure as well as by heat, so that the instrument would be affected by variations of the barometer, though the temperature should be quite stationary.

Fig. 4.



75. For these reasons, the common air-thermometer is rarely employed; but a modification of it, described in 1804, by Leslie, in his Essay on Heat, under the name of *Differential Thermometer*, is entirely free from the last objection, and is admirably fitted for some special purposes. This instrument was invented about a century and a half ago by Sturmius, professor of mathematics at Altdorff, but like other air-thermometers it had fallen into disuse, till it was again brought into notice by Leslie. As now made, it consists of two thin glass balls joined together by a tube, bent twice at a right angle, as represented in the annexed figure. Both balls contain air, but the greater part of the tube is filled with sulphuric acid coloured with carmine. It is obvious that the instrument cannot be affected by any change of temperature acting equally on both balls; for as long as the air within them expands or contracts to the same extent, the pressure on the opposite surfaces of the liquid, and consequently its position, will continue unchanged. Hence the differential thermometer stands at the same point, however the temperature of the medium may vary. But the slightest difference between the temperature of the two balls will instantly be detected; for the elasticity of the air on one side being then greater than that on the other, the liquid will retreat from the ball whose temperature is highest.

Still another modification of this instrument was introduced some years since by Dr. Howard of Baltimore. He substituted ether for sulphuric acid; and having expelled the air by boiling the ether, the tube was hermetically sealed. The bulbs are therefore filled with the vapor of ether, which is vastly more sensitive than atmospheric air.

76. Solid substances are not better suited to the construction of thermometers than gases; for while the expansion of the latter is too great, that of the former is so small that it cannot be measured except by the adaptation of complicated machinery. Liquids which expand more than the one and less than the other, are exempt from both extremes; and, consequently, we must search among them for a material with which to construct a thermometer. The principle of selection is plain. A material is required whose expansions are uniform and whose boiling and freezing points are very remote from each other. Mercury fulfils these conditions better than any other liquid. No fluid can support a greater degree of heat without boiling than mercury, and none, except alcohol and ether, can endure a more intense cold without freezing. It has, besides, the additional advantage of being more sensible to the action of heat than other liquids, while its dilatations between 32° and 212° are almost perfectly uniform. Strictly speaking, the same quantity of heat does occasion a greater dilatation at high than at low temperatures, so that, like other fluids, it expands in an increasing ratio. But it is remarkable that this ratio, within the limits assigned, is exactly the same as that of glass; and, therefore, if contained in a glass tube, the increasing expansion of the vessel compensates for that of the mercury.

77. It will be unnecessary here to give a *minute* description of the method of making thermometers, as, at the present day, they can be everywhere obtained at a very moderate price. "Besides, the construction, though simple in theory, is difficult in practice. It requires great tact and dexterity to produce one of very moderate goodness; and without steadily watching the process as performed by another, or previously possessing much practical knowledge in glass-blowing, &c., it would be a vain attempt."—*Faraday's Chemical Manipulation*, p. 144.

78. Ordinary thermometers consist simply of a glass tube of an exceedingly small bore with a bulb blown at one extremity, and filled with mercury to about one-third the height of the stem. The air being expelled, the tube is hermetically sealed, and the freezing point ascertained by holding it a short time in water containing ice, and the boiling point by holding it in the same manner in boiling water. It is necessary that these two points should be accurately determined, in order that the indications of different instruments may be compared with each other.

79. Having determined these points, the intervening space is to be divided into equal parts, called degrees; and in fixing upon the proper number, regard to convenience alone would seem to be our guide. Unfortunately there have been different

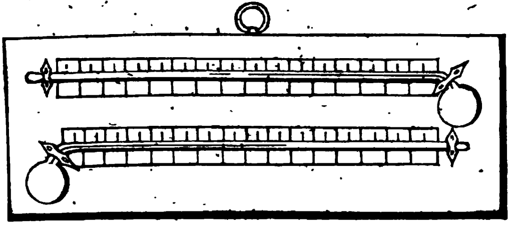
opinions with regard to this point, and no less than three different scales are in use. In Fahrenheit's thermometer, which is chiefly used in this country and in England, the space between the freezing and boiling points of water is divided into 180 parts, and the zero is placed 32 degrees below the freezing point, so that the boiling point is at 212. In the centigrade thermometer, which is generally used in France, the space is divided into 100 parts, zero being at the freezing point, and of course the boiling point is at 100. In Reaumur's thermometer the beginning of the scale or zero is at the freezing point, but the boiling point is at 80. This thermometer is used in Germany and Russia.

But the numbers 180, 100, and 80, which severally represent the number of degrees on the above scales, are to each other as 9, 5, and 4. Recollecting, therefore, that the zero of Fahrenheit is 32 degrees below that of the other scales, the expert arithmetician will find no difficulty in reducing the degrees of one scale to those of another.

81. Below zero of each of the scales, and above the boiling point, degrees are usually marked of precisely equal magnitude with those of other parts of the scale. Temperatures below zero are usually indicated by placing a horizontal line before the figures representing the degrees. Thus —12° means 12 degrees below zero on the scale used. But it will readily be seen that a liquid cannot be used to indicate temperatures below its freezing and above its boiling point. Hence, for temperatures below —39°, at which mercury freezes, alcohol thermometers are always used; but no liquid can sustain a temperature above that of boiling mercury, which is about 662°. And as mercury itself expands in an increasing ratio as the temperature rises, the indications of the mercurial thermometer above 212° cannot be altogether relied on. Alcohol may be used for any degree of cold yet obtained; for though the common alcohol of the shops is readily frozen at very low temperatures, yet in a state of perfect purity it has recently been subjected to a cold of —146°, by Professor Mitchell of Philadelphia, without being congealed.

82. Numerous modifications of the thermometer have appeared at different times, some of them exceedingly curious and adapted to particular purposes; but we will stop to describe a single one only. For many purposes, especially making meteorological observations, it is often very desirable to ascertain the highest and the lowest temperature which has occurred in a given interval of time, during the absence of the observer. An instrument which is now much used for this purpose, called a *Register Thermometer*, was invented by Rutherford of Edinburgh. It in fact consists of two thermometers with separate scales upon the same piece of wood or metal, as seen in the accompanying figure. The stems of both are bent at right

Fig. 5.



angles a little distance from the bulb, so as to be conveniently placed in a horizontal position. The thermometer for ascertaining the *lowest* temperature is made with alcohol, and in the spirit near its surface in the stem is immersed a cylindrical piece of enamel or ivory, of such size as to move freely in the tube. When the spirit contracts by exposure to cold, the small cylinder is drawn towards the bulb owing to its adhesion to the liquid; but, on expanding, the spirit passes readily beyond it, leaving it at the extreme point to which it had been drawn by the previous contraction.

For registering the *highest* temperature, a common mercurial thermometer of the same form as the preceding is employed, having a small cylindrical piece of black enamel or polished steel at the surface of the mercury. When the mercury expands, the enamel is pushed forward; and, as the stem of the thermometer is placed horizontally, it does not recede when the mercury contracts, but remains at the spot to which it had been conveyed by the previous dilatation. The enamel in the mercurial and the ivory in the spirit thermometer, are easily restored to their places by slight percussion when held a little inclined.

83. *Pyrometers.*—Instruments for measuring intense degrees of heat are called *pyrometers*, and must be formed either of solid or gaseous substances. The former alone have been hitherto employed, though the latter, from the greater uniformity with which they expand, are better calculated for the purpose. The action of most pyrometers depends on the elongation of a metallic bar by heat, which seems very simple, but in their construction several difficulties are to be encountered at the outset, which seem almost insuperable. A metal is required which is sufficiently infusible, capable of withstanding the action of fire, and of uniform expansibility; and besides this, at high temperatures it is found very difficult to measure these expansions with sufficient accuracy.

The best pyrometer hitherto constructed is that of Daniel of London, which may be used with facility and appears susceptible of great precision. It consists of a bar of platinum or soft iron, so placed in a case of black-lead earthenware, that when exposed to a high temperature, the bar, expanding more than the case, pushes forward an index of porcelain. The expansions of the bar probably are not strictly uniform at different temperatures, but still they afford a good practical index of the relative intensity of different fires, and will be an exact measure of temperature when the precise rate of expansion shall have been determined.

The pyrometer of Wedgewood, to which reference is often made in books of science, acts on a different principle; but as it is no longer used, in consequence of its great inaccuracy, no description of it is given.

LIQUEFACTION.

84. All bodies are either solid, liquid, or gaseous; and the form they assume depends on the relative intensity of cohesion and repulsion. Should the repulsive force be comparatively feeble, the particles will adhere so firmly together, that they cannot move freely upon one another, thus constituting a solid. If cohesion is so far counteracted by repulsion that the particles move on each other freely, a liquid is formed, and, should the cohesive attraction be entirely overcome, so that the particles not only move freely on each other, but would, unless restrained by external pressure, separate from one another to an indefinite extent, an aeriform substance will be produced.

85. Now the property of repulsion is manifestly owing to heat; and as it is easy within certain limits to increase or diminish the quantity of this principle in any substance, it follows that the forms of bodies may be made to vary at pleasure: that is, by heat sufficiently intense every solid may be converted into a liquid, and every liquid into vapor. This inference is so far justified by experience that it may justly be considered as a law. The converse ought also to be true, and, accordingly, several of the gases have already been condensed into liquids by means of pressure, and liquids have been solidified by cold. The temperature at which liquefaction takes place is called the melting point, or point of fusion; and that at which liquids solidify, their freezing point, or point of congelation. Both these points are different for different substances, but uniformly the same, under similar circumstances, in the same body.

86. The most important circumstance relative to liquefaction is the discovery of Dr. Black, that a large quantity of heat disappears, or becomes insensible to the thermometer, during the process. If a pound of water at 32° be mixed with a pound of water at 172°, the temperature of the mixture will be intermediate between them, or 102°. But if a pound of water at 172° be added to a pound of ice at 32°, the ice will quickly dissolve, and on placing a thermometer in the mixture, it will be found to stand, not at 102°, but at 32°. In this experiment,

the pound of hot water, which was originally at 172°, actually loses 140° of heat, all of which enters into the ice, and causes its liquefaction, without affecting its temperature; whence it follows that a quantity of heat becomes insensible during the melting of ice, sufficient to raise the temperature of an equal weight of water by 140°. This explains the well-known fact, on which the graduation of the thermometer depends,—that the temperature of melting ice and snow never exceeds 32°. All the heat which is added becomes insensible, till the liquefaction is complete.

87. The loss of sensible heat which attends liquefaction seems essentially necessary to the change, and for that reason is frequently called the *heat of fluidity.* The actual quantity of heat required for this purpose varies with the substance, as is proved by the following result obtained by Irvine. The degrees indicate the extent to which an equal weight of each material may be heated by the heat of fluidity which is proper to it.

	Heat of Fluidity.		*Heat of Fluidity.*
Sulphur	143.68° F.	Zinc	493° F.
Spermaceti	145°	Tin	500
Lead	162	Bismuth	550
Beeswax	175		

That a large quantity of caloric is absorbed during the melting of ice may be shown very satisfactorily by the following familiar experiment:—Let a quantity of ice or snow be exposed to a uniform fire, and the number of seconds noted that are required for it to melt, and also the further number of seconds that elapse before it begins to boil. Now as the heat is supposed to be uniform, the quantities of caloric absorbed will be as the times; and we shall therefore have the ratio of the quantity of caloric required to melt the ice, to the quantity required to raise the temperature of the water, (after the ice is melted,) to its boiling point. The times will be found about as 140 to 180, or 7 to 9.

88. Liquefaction is generally produced by the direct application of heat, but this is not always necessary; and the great absorption of caloric becomes still more evident when it can be effected by other means. Examples of this kind are furnished in freezing mixtures, in which liquefaction more or less rapid is produced by the affinity of the substances used for each other. Thus when snow and common salt are mixed together, in consequence of their affinity for each other, they combine rapidly, passing at the same time from the solid to the liquid form, and producing intense cold by the absorption of caloric from surrounding objects. A mixture of snow and chloride of calcium produces much greater cold; and many other mixtures may be used for this purpose, even without any snow or ice. Indeed caloric is always absorbed during the solution of a salt; and the amount of the absorption, and, of course, the

intensity of the cold produced, will depend upon the rapidity with which the solution takes place.*

89. The fact is therefore clearly established that solids in changing to liquids absorb caloric; and, of course, when liquids congeal, caloric must be given out: — the caloric that was before absorbed now becomes sensible. This is not merely a deduction of theory; it is supported by facts. The freezing point of water is at 32°, but by keeping it very tranquil it may be cooled down to 21° and even lower; but, as soon as congelation commences, the temperature rises to 32° in consequence of the caloric which is given out by the portion which has become solid. Saturated solutions of several of the salts made at elevated temperatures, upon being slowly cooled, exhibit the same phenomenon.

A beautiful experiment may be performed by dissolving two or three parts of sulphate of soda in one part of hot water, and setting it aside in a closely corked vial till it cools. If now the cork is removed, or the vessel violently agitated, the salt will immediately crystalize, and a thermometer placed in it will rise several degrees.

90. We cannot but notice here the beautiful and unexpected manner by which nature, to some extent at least, checks the cold of winter, which might otherwise be destructive. The cold atmosphere causes large quantities of water to congeal, but at the same time heat is given out which without question prevents so great a reduction of temperature as might, but for this circumstance, be experienced.

The peculiar means by which the temperature is limited in the opposite direction, will be noticed more appropriately in another place.

91. The important facts noticed above are beautifully explained by a theory proposed by Dr. Black. He supposes caloric to exist in two states, *latent* or *combined*, and *free* or *uncombined*. When a solid becomes liquid, he supposes a quantity of caloric combines with that substance, and thus becomes latent or insensible and incapable of acting on the thermometer; and therefore liquefaction always takes place gradually. On the other hand, when a liquid is cooled down to a certain point, it parts with its caloric of fluidity, which now becomes sensible, and takes the solid form.

92. The greatest cold yet produced by means of freezing mixtures is something less than 100 degrees below zero, but by means of solid carbonic acid and ether, under an exhausted receiver, a temperature has been attained as low as —166 degrees. Nothing, however, seems as yet to be determined concerning the absolute zero; nor is it supposed to be possible to deprive a body entirely of its caloric.

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* Numerous recipes for forming freezing mixtures, both with and without ice or snow, are given in more extended works on chemistry, to which the intelligent student is referred.

VAPORIZATION.

93. Aeriform substances are commonly divided into vapors and gases. The character of the former is that they may be readily converted into liquids or solids, either by a moderate increase of pressure, the temperature at which they were formed remaining the same, or by a moderate diminution of that temperature, without change of pressure. Gases, on the contrary, retain their elastic state more obstinately; they are always gaseous at common temperatures, and, with one or two exceptions, cannot be made to change their form, unless by being subjected to much greater pressure than they are naturally exposed to. Several of them, indeed, have hitherto resisted every effort to compress them into liquids. The only difference between gases and vapors is in the relative forces with which they resist condensation.

94. Heat appears to be the cause of vaporization, as well as of liquefaction; and a sufficiently intense heat would doubtless convert every liquid and solid into vapor. Some bodies, however, resist the strongest heat of our furnaces without vaporizing. These are said to be *fixed* in the fire: those which, under the same circumstances, are converted into vapor, are called *volatile*.

95. The disposition of various substances to yield vapor is very different; and the difference depends doubtless on the relative power of cohesion with which they are endowed. Liquids are, in general, more easily vaporized than solids, as would be expected from the weaker cohesion of the former. Some solids, such as arsenic and sal ammoniac, pass at once into vapor without being liquefied; but most of them become liquid before assuming the elastic condition.

96. Vapors occupy more space than the substances from which they were produced. Gay Lussac found that water in passing into vapor from its point of greatest density, expands to 1696 times* its volume, alcohol to 659 times, and ether to 443 times, each vapor being at a temperature of 212° F. and under a pressure of 29.92 inches of mercury. This shows that vapors differ in density. Watery vapor is lighter than air at the same temperature and pressure, in the proportion of 1000 to 1604; or the density of air being 1000, that of watery vapor is 625. The vapor of alcohol, on the contrary, is half as heavy again as air; and that of ether is more than twice and a half as heavy.

97. Vaporization may, perhaps, be more conveniently studied under the two heads, *Ebullition* and *Evaporation*. In the first, the production of vapor is usually beneath the surface where

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*According to Donovan (Chemistry, page 52,) water in passing into steam expands 1719 times, the water being supposed to be at 60° and the steam at 212°. Ordinarily we may say a cubic inch of water will form a cubic foot of steam.

the heat is applied, and is so rapid that its escape through the liquid gives rise to a visible commotion in it; in the second, it passes off quietly and insensibly from the surface.

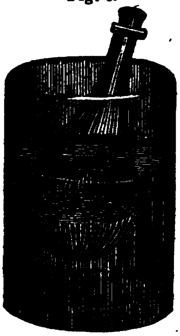
98. *Ebullition.*—The temperature at which vapor rises with sufficient freedom for causing the phenomena of ebullition is called the *boiling point.* The heat requisite for this effect varies with the nature of the liquid. Thus, sulphuric ether boils at 96°, alcohol at 176, and pure water at 212; while oil of turpentine must be raised to 316°, and mercury to 662, before either exhibits marks of ebullition. The boiling point of the same liquid is constant, so long as the necessary conditions are preserved; but it is liable to be affected by several circumstances. The nature of the vessel has some influence upon it. Thus Gay Lussac observed that pure water boils precisely at 212° in a metallic vessel, and at 214° in one of glass, owing apparently to its adhering to glass more powerfully than to a metal. It is likewise affected by the presence of foreign particles; when a few iron filings are thrown into water, boiling in a glass vessel, its temperature quickly falls from 214° to 212, and remains stationary at the latter point. But the circumstance which has the greatest influence over the boiling point of liquids is variation of pressure. All bodies upon the earth are constantly exposed to considerable pressure; for the atmosphere itself presses with a force equivalent to a weight of 15 pounds on every square inch of surface. Liquids are exposed to this pressure as well as solids, and their tendency to take the form of vapor is very much counteracted by it. In fact, they cannot enter into ebullition at all, till their particles have acquired such elastic force as enables them to overcome the pressure upon their surfaces; that is, till they press against the atmosphere with the same force as the atmosphere against them. Now the atmospheric pressure is variable, and hence it follows that the boiling point of liquids must also vary.

99. The pressure of the atmosphere is equal to a weight of 15 pounds on every square inch of surface, when the barometer stands at 30 inches, and then only does water boil at 212°. If the pressure be less, that is, if the barometer fall below 30 inches, then the boiling point of water, and other liquids, will be lower than usual; or if the barometer rise above 30 inches, the temperature of ebullition will be proportionally increased. On this account water boils at a lower temperature on the top of a hill than in the valley beneath it; for as the column of air diminishes in length as we ascend, its pressure must likewise suffer a proportional diminution. The ratio between the depression of the boiling point and the diminution of the atmosphere is so exact that it has been proposed as a method for determining the height of mountains. An elevation of 530 feet makes a diminution of one degree of Fahrenheit.

100. The influence of the atmosphere over the point of ebullition is best shown by removing its pressure altogether. It is found

that in a perfect vacuum liquids boil at a temperature 140 degrees lower than in the open air. Thus water boils in a vacuum at 72°, alcohol at 36°, and ether at —46°. A liquid, therefore, is not necessarily hot because it boils; but the particular temperature required to produce this effect will depend upon circumstances, as seen above.

Fig. 6.



The effect of diminished atmospheric pressure may also be shown by filling a Florence flask about half full of water, and causing it to boil a minute briskly over a spirit-lamp, so as to expel entirely the air contained in it. If now a cork be firmly pressed into the neck of the flask, and the lamp instantly removed, the water will continue to boil in consequence of the diminished pressure occasioned by the condensation of the steam above the water. If the flask be immersed in cold water or snow, or ice be thrown upon it above the water, the steam will be condensed more rapidly, and the boiling will be more violent.

When the contents of the flask have become entirely cold, on agitating it, the water will be observed to strike the inside of the glass like shot or hail, or it may be thrown from side to side in an unbroken mass like a solid. This is occasioned by there being no atmosphere within to break the mass into foam as is usually the case.

101. Water cannot be heated under common circumstances beyond 212°; because it then acquires such expansive force as enables it to overcome the atmospheric pressure, and fly off in the form of vapor. But if subjected to sufficient pressure, it may be heated to any extent without boiling. This is best done by heating water while confined in a strong copper vessel, called Papin's digester. In this apparatus, on the application of heat, a large quantity of vapor collects above the water, and checks ebullition by the pressure which it exerts upon the surface of the liquid. There is no limit to the degree to which water may thus be heated, provided the vessel is strong enough to confine the vapor; but the expansive force of steam under these circumstances is so enormous as to overcome the greatest resistance.

It has been determined by experiment that the tension of steam is equal to two atmospheres at about 250°, three atmospheres at 275°, and four, at about 293.7°. To produce a pressure of twenty-five atmospheres, a temperature of 439° only is required. This would be about sufficient to melt tin.

102. The elasticity of steam is employed as a moving power in the steam-engine. The construction of this machine depends on two properties of steam, namely, the expansive force communicated to it by heat, and its ready conversion into water by cold. The effect of both these properties is well shown by a little instrument devised by Wollaston. It consists of a cylin-

drical glass tube, six inches long, nearly an inch wide, and blown out into a spherical enlargement at one end. A piston is accurately fitted to the cylinder, so as to move up and down the tube with freedom. When the piston is at the bottom of the tube, it is forced up by causing a portion of water, previously placed in the ball, to boil by means of a spirit-lamp. On dipping the ball into cold water, the steam which occupies the cylinder is suddenly condensed, and the piston forced down by the pressure of the air above it. By the alternate application of heat and cold, the same movements are reproduced, and may be repeated for any length of time.

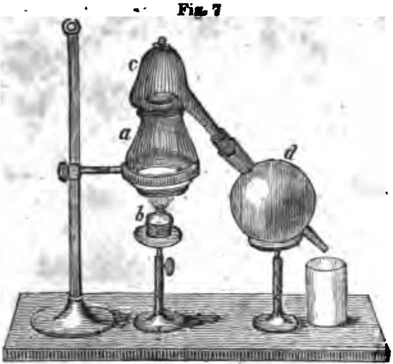
The moving power of the steam-engine is the same as in this apparatus. The only essential difference between them is in the mode of condensing the steam. In a steam-engine, the steam is condensed in a separate vessel, called the *condenser*, where there is a regular supply of cold water for the purpose. By this contrivance, which constitutes the great improvement of Watt, the temperature of the cylinder never falls below 212 degrees.

103. The formation of vapor is attended, like liquefaction, with loss of sensible heat. This is proved by the well-known fact that the temperature of steam is precisely the same as that of the boiling water from which it rises; so that all the heat which enters into the liquid is solely employed in converting a portion of it into vapor, without affecting the temperature of either in the slightest degree, provided the latter is permitted to escape with freedom. The heat which then becomes latent, to use the language of Black (91), is again set free when the vapor is condensed into water. The exact quantity of heat rendered insensible by vaporization, may, therefore, be ascertained by condensing the vapor into cold water, and observing the rise of temperature which ensues. From experiments conducted on this principle, it appears that steam of 212°, in being condensed into water of 212°, gives out as much heat as would raise the temperature of an equal weight of water by 950 degrees, all of which had previously existed in the vapor without being sensible to a thermometer.

104. The process of *distillation* consists simply in evaporating a substance and again condensing the vapor by causing it to come in contact with a cold surface. This is usually accomplished by having a tube of considerable length leading from the top of a close boiler and passing in the form of a spiral through a vessel which is kept filled with cold water.

Distillation on a small scale may be very well performed in a glass *alembic*, by means of a spirit-lamp, as represented in Fig. 7. The body of the alembic *a* is to receive the liquid to be distilled, and the capital *c* is so constructed that any liquid which is condensed in it does not again descend to *a*, but passes into *d* the receiver. The vapor is formed in *a* by

Fig. 7



the heat of the lamp *b*, and is condensed in *c* and *d*, in the last of which it is collected. The receiver *d* is to be kept cold by the constant application of water if necessary. Any uncondensed vapor is permitted to escape from *d*, where also the liquid distilled may also be received as it forms.

By this process volatile substances, whether liquid or solid, may be separated from those that are fixed, or even from such as are less volatile than themselves. Water is distilled to purify it from salts or other substances it may contain in solution or suspension; and alcohol by distillation is separated from water which is less volatile than itself, as well as from fixed substances. When the less volatile substance is retained, the term *condensation* is generally used. Thus the condensation of sulphuric acid consists merely in the expulsion of the water it contains by heat.

The term *sublimation* is generally used when a solid is subjected to this process. Thus sulphur, vermilion, and corrosive sublimate, are purified by sublimation, which, however, in principle is precisely the same as the distillation of a liquid. But the terms are in some cases used synonymously.

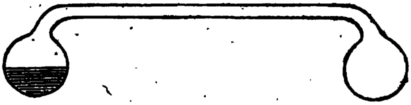
105. *Evaporation.*—Evaporation as well as ebullition consists in the formation of vapor, and the only assignable difference between them is that the one takes place quietly, the other with the appearance of boiling. Evaporation occurs at common temperatures. This fact may be proved by exposing water in a shallow vessel to the air for a few days, when it will gradually diminish, and at last disappear entirely. Most liquids, if not all of them, are susceptible of this gradual dissipation; and it may also be observed in some solids, as for example in camphor. Evaporation is much more rapid in some liquids than in others, and it is always found that those which have the lowest boiling point evaporate with the greatest rapidity. Thus alcohol, which boils at a lower temperature than water, evaporates also more freely; and ether, whose point of ebullition is yet lower than that of alcohol, evaporates with still greater rapidity.

The chief circumstances that influence the process of evaporation are extent of surface, and the state of the air as to temperature, dryness, stillness, and density.

106. Caloric is absorbed during the slow conversion of a liquid into a gas in evaporation as well as during ebullition, and it of course follows that cold should be produced. This fact may readily be proved by letting a few drops of ether evaporate from the hand, when a strong sensation of cold will be excited; or if the bulb of a thermometer, covered with lint, be moistened with ether, the production of cold will be marked by the descent of the mercury. But to appreciate the degree of cold which may be produced by evaporation, it is necessary to render it very rapid and abundant by artificial processes; and the best means of doing so, is by removing pressure from the surface of volatile liquids. Water placed under the exhausted receiver of an air-pump evaporates with great rapidity, and so much cold is generated as would freeze the water, did the vapor continue to rise for some time with the same velocity. But the vapor itself soon fills the vacuum, and retards the evaporation by pressing upon the surface of the water. This difficulty may be avoided by putting under the receiver a substance, such as sulphuric acid, which has the property of absorbing watery vapor, and consequently of removing it as quickly as it is formed. Such is the principle of Leslie's method for freezing water by its own evaporation.

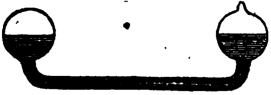
107. The action of the cryophorus, an ingenious contrivance of Wollaston, depends on the same principle. It consists of two glass balls, perfectly free from air, and joined together by a tube, as here represented.

Fig. 8.



One of the balls contains a portion of distilled water, while the other parts of the instrument, which appear empty, are full of aqueous vapor, which checks the evaporation from the water by the pressure it exerts upon its surface. But when the empty ball is plunged into a freezing mixture, all the vapor within it is condensed; evaporation commences from the surface of the water in the outer ball, and it is frozen in two or three minutes by the cold thus produced.

Fig. 9.



The *pulse-glass* is a well-known toy constructed on the same principle, only alcohol is used instead of water. On one of the bulbs is seen a small projection, through which when open the alcohol is introduced, and from which the air is expelled by the vapor of alcohol, which is made to boil by being held over a spirit-lamp. While the vapor of alcohol is escaping, the point is suddenly closed by the blowpipe, and nothing of course is contained within but alcohol and its vapor. By grasping one of the bulbs firmly in the hand, the vapor by its expansion will immediately force all the liquid into the other; and the moment it has all passed through the stem an appearance of violent ebullition is produced, attended by a distinct sensation of cold in the hand which grasps the bulb. This is occasioned by the rapid evaporation of the film of liquid lining the inside of the bulb.

108. The effect of evaporation in withdrawing heat is admirably illustrated by the process of perspiration. The natural temperature of the human body is about 98°, but when we take active exercise, or when we are exposed to a great degree of heat, there is a tendency to a rise of temperature above that which is conducive to health; and the most injurious effects would ensue, if they were not prevented by the reduction of the temperature occasioned by perspiration.

109. Examples of the power of the human body to sustain great and apparently even dangerous elevations of temperature are on record. It is well known that individuals have voluntarily exposed themselves for several minutes, in ovens, to temperatures even a hundred degrees above that of boiling water, without suffering any injury. The very rapid perspiration that takes place in such circumstances, prevents the destructive elevation of temperature in the system which would otherwise take place.

In the same manner the high temperature of summer is mitigated by the evaporation of water from the surface of the earth. Some time since (90) we saw that the caloric which is given out by the freezing of water in winter, prevents the low reduction of temperature that would otherwise be experienced; and we cannot here less admire the wonderful provision of Providence by which, on the other hand, the excessive heat of summer is, to some extent, limited.

110. Porous earthen vessels are often used in hotels and other places in warm weather to contain water for drinking. A portion of the water gradually exudes through the vessels, and evaporates from the surface, by which that within is kept several degrees colder than the temperature of the atmosphere. Such vessels are said to be much used in Spain, where they are called *alcarrazas*. People crossing the deserts of Arabia in caravans are said sometimes to load camels with earthenware bottles filled with water, which is kept cool by wrapping the jars with linen cloths, and keeping them moist with water.

111. Liquids, which evaporate more rapidly than water, cause a still greater reduction of temperature. The cold produced by the evaporation of ether in the vacuum of the air-pump, is so intense as under favorable circumstances to freeze mercury.

Water may very readily be frozen by the evaporation of ether in the open air in the warmest weather, by the following method. Fill a small thin vial with water and wrap around it a piece of fine muslin, and suspend over it a dropping tube filled so that the muslin may be kept constantly wet with it. Evaporation will take place with such rapidity that the water in the vial will in a short time be frozen. The experiment will require less time if the vial is suspended by a small wire and placed in a gentle current of air.

112. A great advance has recently been made in this department of experimental science by the solidification of carbonic acid gas, which is first condensed into a liquid by pressure, and then the liquid is solidified or frozen by its own rapid evaporation. A full description of the process will shortly be given. Sulphurous acid gas may also be condensed into a liquid, which, on being permitted to issue into the open air, produces by its own evaporation sufficient cold to freeze mercury.

113. Scientific men have differed concerning the cause of evaporation. It was once supposed to be owing to chemical attraction between the air and water, and the idea is at first view plausible, since a certain degree of affinity does to all appearance exist between them. But it is nevertheless impossible to attribute the effect to this cause. For evaporation takes place equally in a vacuum as in the air; nay, it is an established fact that the atmosphere positively retards the process, and that one of the best means of accelerating it is by removing the air altogether.

Experiments prove that caloric is the true and only cause of the formation of vapor. Evaporation is indeed more rapid in proportion as the atmospheric pressure is diminished, but the actual quantity of vapor that can exist in a given space, is dependent solely upon the temperature.

114. The presence of aqueous vapor in the atmosphere is owing to evaporation, which goes on to a certain extent even at low temperatures, and it is probable the atmosphere is never absolutely free from vapor; but the quantity present is very variable, in consequence of the continual change of temperature to which the air is subject. But even when the temperature is the same, the quantity of vapor is still found to vary; for the air is not always in a state of saturation. At one time it is excessively dry, at another it is fully saturated; and at other times it varies between these extremes.

115. The variable condition of the atmosphere as to saturation with moisture is determined by an instrument called a *hygrometer*, several of which of different constructions are in use; but none of them are of sufficient importance to claim a description here.

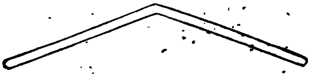
116. Watery vapor, when it rises in the atmosphere, is perfectly invisible, but in certain circumstances which do not seem to be well understood it becomes visible, constituting mists and clouds which are constantly seen floating in the air. This moisture, after remaining awhile suspended in the air, is again

condensed, and descends to the earth in the form of rain. Rain, it is well known, never falls unless the sky is cloudy, nor unless that peculiar kind of dense black cloud appear known by the name of *rain-cloud;* but the manner in which rain is formed, though different theories have been proposed to account for it, must yet be considered as involved in obscurity.

All the accumulations of water upon the surface of the earth are thus subjected to a constant natural distillation; the impurities with which they are charged remain behind, while the pure water in the form of vapor rises in the air to be again diffused over the earth.

117. *Constitution of the Gases with respect to Heat.*—Recent experiments by Faraday, Thillorier, Mitchell, and others, appear to justify the opinion that gases are merely the vapors of extremely volatile liquids. Most of these liquids, however, are so volatile that their boiling point, under the atmospheric pressure, is lower than any natural temperature; and hence they are always found in the gaseous state. By subjecting them to a great pressure, their elasticity is so far counteracted that they become liquid; and by reducing the temperature of the liquids very low, several of them have even been congealed.

Fig. 10.



The usual method of liquefying a gas is to put the materials for preparing it into a strong glass tube, keeping them apart if necessary, and then sealing the tube hermetically, or closing it with a cap* and some strong cement. The substances may then be brought together and heat applied if necessary; and the gas as it is generated being unable to escape, when sufficient pressure is produced, is converted into a liquid and collected in the upper part of the tube. These experiments are attended with danger from the bursting of the tubes, and should never be attempted but with the utmost caution.

In some cases it will be found most convenient to use straight tubes; but in others it will be best to have them bent as in the figure.

Different gases require very different forces to compress them into the liquid form, for while sulphurous acid gas, at the temperature of 45°, requires only two atmospheres, carbonic acid gas at 32° requires no less than thirty-six atmospheres.

120. Carbonic acid, as well as several other of the gases, have been solidified; which is done by exposing them, in the liquid state, to the action of intense cold. To prepare solid carbonic acid, it is necessary to construct a very strong apparatus with a generator to receive the materials for forming the liquid acid, and a smaller receiver, into which this liquid is

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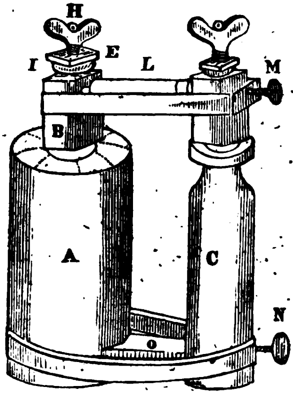
* Dr. Torrey.

to be distilled pure. If a jet of this liquid be now permitted to escape into the open air, a large part of it immediately evaporates, producing such intense cold that the remainder is actually frozen, and appears like very fine moist snow. In the open air it soon escapes in vapor; but covered with cotton, so as to protect it from the atmosphere, small lumps of it may be preserved for hours.

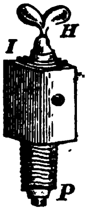
119. An apparatus like the following, for solidifying carbonic acid, answers the purpose perfectly well, and can be made at a very trifling expense.

Fig. 11.



The generator A, fig. 11, may be made of a common mercury flask, having the aperture at the neck a little enlarged so as to be about an inch and a quarter in diameter. A plug of cast-steel B is then made of a bar two inches at least in diameter, and turned with a wide and smooth shoulder so as to fit accurately upon a collar of block-tin, when screwed into its place, as represented in the figure. The valves, which are the most difficult part to construct, on account of the great pressure that is to be overcome, are inserted in the plugs, a second one of which, precisely like the preceding, is made to screw into the receiver C. Into the upper end of each plug, a hole an inch in diameter is bored about one inch deep, and terminates in a conical point; from which an aperture, a tenth of an inch in diameter is bored quite through the plug. E H is composed of two parts, so constructed that when screwed firmly into the cast-steel plug, and the part H which terminates in a conical point screwed down, all escape of the gas from the generator is effectually prevented. When the part H is screwed upward, the escape of the gas around E is prevented by the firm pressure of the shoulder of E upon the washer I, and a shoulder upon the lower part H, which presses against the bottom of E, and produces the same effect with regard to the escape of the gas around the thread of the screw H.

Fig. 12.



Instead of the valve described above, the following, invented by Torrey, answers better for the generator, as the passage at the bottom of the plug is not liable, as in the other construction, to be closed by the sulphate of soda which is formed. The part H extends quite through the plug, having at the lower extremity a nut P attached firmly by a screw and soldered. Now when the screw H is turned upward, the thread on which extends from I downward about an inch, the nut P perfectly closes the passage below, but by turning the screw down the passage through the plug is opened at P and closed at I, allowing the gas to escape laterally as in the other construction.

The receiver C is easily made of common boiler iron, and should be about two inches internal diameter, and of the same height as the generator, which will make it of the capacity of about a pint. The tube L should screw into the plug connected with the receiver, having its other extremity terminate in a conical point to fit into a cavity prepared for it in the other plug. By means of the stirrup-screws M and N, and the block of wood O, the receiver may then be firmly screwed in its place; and when both the valves are open, there will be a free passage between it and the generator, but no communication of either with the open air.

To make use of this apparatus, the generator and receiver are separated, and the plug B being removed, 2½ pounds of bicarbonate of soda, made into a paste with the same weight of water, are introduced into A, and 21½ ounces of strong sulphuric acid are poured into several copper vessels made a little shorter than the length internally of the generator, and of such a diameter that they will just pass the aperture. These being nearly filled with acid are dropped into the generator, which, after the plug B is inserted, is allowed to lie on one side for fifteen or twenty minutes, and several times rolled over, to mix the acid with the soda. The receiver is then attached to it as seen in the figure, by means of the stirrup-screws M and N; and, if kept sufficiently cool by means of ice, the liquid carbonic acid formed in A will shortly be distilled over into C, the passage between them being of course previously opened.

The valves are now to be closed, and the receiver, which contains the liquid carbonic acid, separated from the generator. A small tin cup (not represented in the figure) is then to be attached to the tube L, to receive the jet of acid from the receiver. It is essential that the *liquid* acid should escape into this cup, which is effected by having a small tube pass from the steel plug nearly to the bottom of the receiver, or by inverting the receiver before opening the valve.

The apparatus should be well tested, at least three times, before running any risk by venturing to handle it while charged. This is best done by means of a hydraulic press; but the same object may be accomplished very effectually by standing the apparatus when charged in a tub of water heated to about 150°; so that when the apparatus and water have attained the same temperature, it shall not be lower than 130°. If a more severe test is desired, the water may be made still hotter.

Gauges for measuring the amount of pressure at different temperatures, may be attached to this apparatus, if desired, in the usual manner.—(*Sil. Journal*, xxviii. p. 297.)

In constructing an apparatus, care should always be taken to make the receiver of not more than one-fifth the capacity of the generator, and probably it would be still better if it were not more than one-sixth or one-seventh. The quantity of materials used should also be just sufficient *very nearly* to fill the generator.

SECTION III.

SPECIFIC CALORIC.

120. The construction and uses of the thermometer have been described in a preceding section (73). Though this instrument is one of the most valuable for philosophical research, it must be confessed that the sum of information which it conveys is small.

It does indeed point out a difference in the temperature of two or more substances with great nicety; but it does not indicate how much heat any body contains. It does not follow, because the thermometer stands at the same elevation in any two bodies, that they contain equal quantities of heat; nor is it right to infer that the warmer possesses more of this principle than the colder. The thermometer gives the same kind of information which may be discovered, though less accurately, by the feelings; it recognizes in bodies that state of caloric alone which affects the senses with an impression of heat or cold,—the condition expressed by the word *temperature.* All we learn by this instrument is, whether the temperature of one body is greater or less than that of another; and if there is a difference, it is expressed numerically, namely, by the degree of the thermometer. But it must be remembered that these degrees are parts of an arbitrary scale, selected for convenience, without any reference whatever to the actual quantity of heat present in bodies.

121. A little reflection will evince the propriety of these remarks. If two glasses of unequal size be filled with water just taken from the same spring, the thermometer will stand in each at the same height, though their quantities of heat are certainly unequal. This observation naturally suggests the inquiry, whether different kinds of substances, whose temperature as estimated by the thermometer are the same, contain equal quantities of heat;—if, for example, a pound of iron contains as much heat as a pound of water or mercury. The foregoing remark shows that equality of temperature is not necessarily connected with equality in quantity of heat; and the inference has been amply confirmed by experiment. If equal quantities of water are mixed together, one portion being at 100° and the other at 50°, the temperature of the mixture will be the arithmetical mean or 75; that is, the 25 degrees lost by the warm water will exactly suffice to heat the cold water by the same number of degrees. It is hence inferred that equal weights or measures of water of the same temperature contain equal quantities of heat; and the same is found to be true of other bodies. But if *different substances* are used, the results will be entirely different. For instance, on mixing a pound of mercury at 160° with a pound of water at 40°, a thermometer placed in the mixture will stand at 45°; but if the mercury be at 40° and the water at 160°, the mixture will have a temperature of 155°. If water at 100° be mixed with an equal weight of spermaceti oil at 40°, the mixture will be found at 80°; and when the oil is at 100° and the water at 40°, the temperature of the mixture will be only 60°.

It appears from these facts that the same quantity of heat which imparts 5 degrees of temperature to water, is sufficient to heat an equal weight of mercury 115 degrees; and that the quantity required to heat water 20 degrees, will raise an equal weight of spermaceti oil 40 degrees. Now 5 and 115 are in the ratio of 1 to 23, and 20 is to 40 as 1 to 2; it is hence evident that if equal quantities of heat be added to equal weights of water, spermaceti oil, and mercury, their temperatures in relation to each other will be expressed by the numbers 1, 2, and 23; or, what amounts to the same, in order to increase the temperature of equal weights of those substances to the same extent, the water will require twenty-three times as much heat as the mercury, and twice as much as the oil. The peculiarity exemplified by these substances, and which it would be easy to illustrate by other examples, was first noticed by Black. It is a law, admitted to be universal, and may be thus expressed; that *equal* quantities of different bodies require *unequal* quantities of caloric to heat them equally. This difference in bodies was expressed in the language of Black, by the term *capacity* for heat, but the term *specific heat* is now generally preferred.

122. The fact* that substances of equal temperature contain unequal quantities of heat naturally excites speculation about its cause, and various attempts have been made to account for it. The explanation deduced from the view of Black (86, 91) is the following:—He conceived that heat exists in bodies in two opposite states: in one it is supposed to be in chemical combination, exhibiting none of its ordinary characters, and remaining concealed, without evincing any signs of its presence; in the other, affecting the senses in its passage, determining the height of the thermometer, and in a word giving rise to all the phenomena which are attributed to this active principle.

123. Though it would be easy to start objections to this ingenious conjecture, it has the merit of explaining phenomena more satisfactorily than any view that has been proposed in its place. It is entirely consistent with analogy. For, since heat is regarded as a material substance, it would be altogether anomalous were it not influenced, like other kinds of matter, by chemical affinity; and if this be admitted, it ought certainly, in combining, to lose some of the properties by which it is distinguished in its free state. According to this view, it is intelligible how two substances, from being in the same condition with respect to free heat, may have the same temperature; and yet that their actual quantities of heat may be very different, in consequence of one containing more of that principle in a combined or latent state than the other. But in admitting the plausibility of this explanation, it is proper to remember that

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* This fact was considered very singular and surprising when first discovered, but it certainly is no more so than other analogous facts we meet with in chemistry on every hand. For instance, 32 parts of soda require, to neutralize them, 40 parts of sulphuric acid, but an equal weight of potash requires only two-thirds as much acid;—a fact quite as singular as the one referred to.

it is at present entirely hypothetical: and that the language suggested by a hypothesis should not be unnecessarily associated with the phenomena to which it owes its origin. Accordingly, the word *sensible* is better than *free* heat, and *insensible* preferable to *combined* or *latent* heat; for by such terms the fact is equally well expressed, and philosophical propriety strictly preserved.

124. It is of importance to know the specific heat of bodies. The most convenient method of discovering it is by mixing different substances together in the way just described, and observing the relative quantities of heat requisite for heating them by the same number of degrees. Water is commonly one of the materials employed in such experiments, and it is customary to compare the specific heat of other bodies with that of water.

125. There are several circumstances concerning the specific heat of bodies that are important to be noticed.

Every substance has a specific heat peculiar to itself, which, however, varies if its form or composition is changed. A substance when solid always has a less specific heat than when in the liquid state; thus if the specific heat of water is 10, that of ice is 9. Whether the specific heat is increased when a solid or liquid is changed into a gas, seems not yet to be determined.

126. The specific heat of solids and liquids increases when their temperature is raised; but in gases a similar effect is not produced if they are allowed to expand freely by the increase of temperature. The specific heat of equal weights of the same gas varies as its density and elasticity vary. Thus, when 100 measures of air expand by diminished pressure to 200 measures its specific heat is increased. A thermometer placed within the receiver of an air-pump will always be observed to fall as the air is rapidly exhausted, in consequence of the increased capacity for heat of the air remaining within. So also if the 100 measures of air are suddenly compressed to 50, the specific heat will be diminished and of course the temperature raised.

This fact is beautifully illustrated by the *fire-syringe*, an instrument which consists merely of a tube with an equal straight bore, and a solid piston fitted to it very accurately. When the piston is plunged forcibly into the tube, the air is much condensed before it, by which its temperature is raised in consequence of its specific heat being diminished; and if a little tinder or other highly combustible substance has been previously attached to the lower side of the piston, it will be ignited by the heat produced.

127. Change of density in solids and liquids is also attended by a change of specific heat, and consequently a change of temperature. A piece of metal may be made red-hot by being struck a few smart blows in rapid succession; its density is increased and its specific heat diminished, and the rise of temperature accompanies it as a necessary consequence.

128. So also when sulphuric acid and water are mixed, great heat is produced as a consequence of the condensation that takes place; and the same effect, to some extent, results from mixing alcohol and water.

SECTION IV.

SOURCES OF HEAT.

129. The sources of heat may be reduced to six. 1. The sun. 2. Combustion. 3. Chemical action without combustion. 4. Mechanical action. 5. Electricity. 6. Vital action.

The sun is the great source of heat to our system. The intensity of the solar heat appears to be directly in proportion to the number of rays that can be collected upon a given surface, and at one time philosophers were able to produce a greater heat by collecting the sun's rays by means of the convex lens or concave mirror than by any other means. The only method by which the sun's rays can be made to produce a great heat at a considerable distance, is to combine a great number of plane mirrors in such a manner that all may throw their images of the sun upon the same spot. By an instrument constructed on this principle, it is said, Count Buffon was able to ignite wood, at the distance of 210 feet.

130. The direct rays of the sun seldom produce a temperature above 120°; but under favorable circumstances it may rise as high as 135°, or even higher.

131. Combustion has been defined, intense chemical action, attended by the evolution of light and heat. As the sun is the great source of natural heat, so combustion is almost always resorted to to produce artificial heat.

Various theories have been proposed to account for the caloric that is given out in combustion, but none of them seem to be satisfactory. We shall, however, speak of them more particularly, as well as the general subject of combustion, and several of the other sources of caloric, in other parts of the work.

132. The mechanical method of exciting heat is by friction and percussion. When parts of heavy machinery rub against one another, the heat excited, if the parts of contact are not well greased, is sufficient for kindling wood. The axle-trees of carriages have been burned from this cause, and the sides of ships are said to have taken fire by the rapid descent of the cable. Count Rumford has given an interesting account of the caloric evolved in boring cannon, which was so abundant as to heat a considerable quantity of water to its boiling point. It appears from his experiments, that a body never ceases to give

out heat by friction, however long the operation may be continued; and he inferred from this observation that heat cannot be a material substance, but is merely a property of matter. Pictet observed that solids alone produce heat by friction, no elevation of temperature taking place from the mere agitation of fluids with one another. He found that the heat excited by friction is not in proportion to the hardness and elasticity of the bodies employed. On the contrary, a piece of brass rubbed with a piece of cedar wood produced more heat than when rubbed with another piece of metal; and the heat was still greater when two pieces of wood were employed.

CHAPTER II.

LIGHT.

SECTION I.

PHYSICAL PROPERTIES.

133. Two theories have long prevailed concerning the nature of light, called the *corpuscular* and the *undulatory* theories.

On the corpuscular theory, which was adopted by Newton, light is supposed to be material, and to consist of inconceivably minute particles, which, however, are too subtile to exhibit the common properties of matter. These particles emanating from luminous bodies, such as the sun, the fixed stars, and incandescent substances, and traveling with immense velocity, excite the sensation of light, it is supposed, by passing bodily through the substance of the eye, and striking against the expanded nerve of vision, the retina. The whole language of optics is founded on this theory.

134. The undulatory theory, which is now generally adopted, denies to light a separate material existence, and ascribes its effects to the vibrations or undulations of a subtile ethereal medium universally present in nature, the pulses of which, in some way excited by luminous objects, pass through space and transparent bodies, and give rise to vision by impressing the retina in the same way as pulsations of air impress the nerve of hearing, to produce the sensation of sound.

135. Some of the phenomena of light, as absorption and refraction, are but obscurely explained on either theory; while other phenomena, though totally inexplicable by the corpuscular or Newtonian, receive a most lucid explanation by the undulatory theory. The latter therefore is now considered alone

suitable to the advanced state of the science. We shall, however, proceed to state the laws of light, so far as is required in an elementary work on chemistry, in the ordinary language which is founded, as has been remarked, on the Newtonian theory, and is analogous to that which has been employed in treating of heat.

136. *Diffusion of Light.*—Light emanates from every visible point of a luminous object, and is equally distributed on all sides, if not intercepted, diverging like radii drawn from the centre to the surface of a sphere. Thus, if a single luminous point were placed in the centre of a hollow sphere, every point of its concavity would be illuminated, and equal areas would receive equal quantities of light. The smallest portion of light which can be separated from contiguous portions is called a *ray of light.* Each ray, when not interrupted in its course, and while it remains in the same medium, moves in a straight line, as is obvious by the appearance of shadows cast by the side of a house, or of a sun-beam admitted through a small aperture into a dark room. Owing to these modes of distribution, it follows that the quantity of light which falls upon a given surface decreases as the square of its distance from the luminous object increases—the same law which regulates the heating power of a hot body (25).

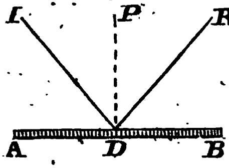
137. The passage of light is progressive, time being required for its motion from one place to another. By astronomical observations it is found that light travels at the rate of nearly 195,000 miles in a second of time, and requires about eight minutes to pass from the sun to the earth. Owing to this prodigious velocity, the light caused by the firing of a cannon or a sky-rocket is seen by different spectators at the same instant, whatever may be their respective distances from the rocket, the time required for light to travel 100 or 1000 miles being inappreciable to our senses.

138. When the light falls upon any body, it may, like radiant heat (25), dispose of itself in three different ways, being *reflected*, *refracted*, or *absorbed.* The phenomena connected with the two former modes of distribution will be considered in succession; while those of absorbed light will be included under the head of *Decomposition of Light.*

139. *Reflection of Light.*—When light passes from one medium into another of different nature or density, a portion of it will always be reflected, whether the media be solid, liquid, or gaseous. Different media, however, differ much in their power of reflection.

Bright metallic surfaces, as polished silver or clean mercury, reflect nearly all the rays which fall upon them; while those which are dull and rough reflect but a few. The reflection of light, like that of heat, takes place at the surface of bodies, and appears to be influenced rather by the condition of the surface than by the nature of the reflecting body. The direction of the reflected ray, whatever may be the nature or figure of the reflecting surface, is regulated by these two laws. 1. The incident and reflected rays always lie in the same plane, which plane is perpendicular to the reflecting surface. 2. The incident and reflected rays always form equal angles with the reflecting surface; or, what amounts to the same, the angle of incidence is always equal to the angle of reflection.

Fig. 13.

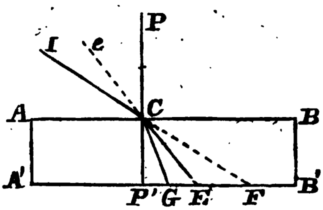


Let AB, figure 13, represent a plane mirror, ID the direction of a ray falling on AB at the point D, and DP a line perpendicular to the mirror AB. Then a plane passing through IDP will be perpendicular to AB, and, by the first law, the reflected ray DR will lie *somewhere* in that plane. Also, by the second law, the angle of reflection RDP, must be equal to the angle of incidence IDP. Hence, as soon as the direction of the incident ray is given, that of the reflected ray is known also.

These laws are not limited in their operation to plane surfaces; but apply equally to those which are curved, whether convex or concave.

140. *Refraction of Light.*—Light traverses the same transparent medium, such as air, water, or glass, in a straight line, provided no reflection occurs, and there is no change of density; but when it passes from one medium into another; or from one part of the same medium into another of a different density, a change of direction always ensues at the plane of junction of the media, except when the ray is perpendicular to that plane.

Fig. 14.



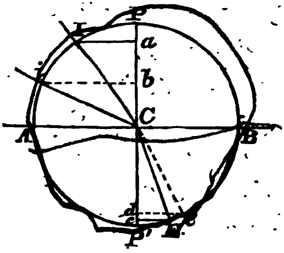
For instance, let A'B, fig. 14, represent a vertical section of a vessel full of water, and PP' the perpendicular to the surface of the water at the point C. Should a ray of light enter the water, perpendicular to its surface, as in the line of PC, it will continue on its course to P' without deviation; but if it descend obliquely, as in the direction of IC, it will suffer a bend at C, and proceed to E, instead of advancing along the dotted line to F. Conversely, were a ray of light to emanate from E and emerge at C, it would not advance to *e*, but take the direction of CI. By comparing the direction of the refracted ray in these two cases in relation to the vertical PP', it will be seen that the ray approaches the perpendicular in entering from air into water, and recedes from it in passing out of water into air. The same remark applies to the passage of light from or into air, into or out of solid or liquid media in general.

141. Bodies differ in their power of refracting light. In general, the denser a substance is, the greater is the deviation which it produces. If in figure 14, sulphuric acid were mixed with the water, the ray IC would be refracted to some point between E and G; and if a solid cake of glass were substituted for that liquid, the refracted ray would be bent down to CG. But this is far from universal:—alcohol, ether, and olive-oil, which are lighter than water, have a higher refractive power. Observation has shown it to be a law, to which no exception is yet known, that oils and other highly inflammable bodies, such as hydrogen, diamond, phosphorus, sulphur, amber, olive-oil, and camphor, have a refractive power which is from two to seven times greater than that of incombustible substances of equal density. But whatever may be the refractive power of bodies in relation to each other, refraction is always governed by the two following laws, discovered in 1618, by Snell, though usually ascribed to Descartes.

1. The direction of the incident and refracted ray is always in a plane perpendicular to the surface common to the media.

2. The sine of the angle of incidence and the sine of the angle of refraction are in a constant ratio for the same media.

Fig. 15.



The first law is similar to the first law of reflection already explained (142.) To explain the second law, let ABE, fig. 15, be a vertical section of a refracting medium, PP′ the perpendicular to it, IC a ray of light incident at C, and CE the refracted ray. Then ICP is the *angle of incidence*, and ECP′ the *angle of refraction*. Also from C as a centre, with any radius CI, and in the plane of the ray ICE, draw a circle; and from the points I and E, where the course of the ray cuts the circle, let fall I*a*, E*c* at right angles to PP′. Then may I*a* be considered the *sine* of the angle of incidence, and E*c* the *sine* of the angle of refraction. The second law denotes that these lines are for each substance in a constant ratio, whatever may be the direction of the incident ray. In the figure the sine of the angle of refraction is to the sine of the angle of incidence as 1 to 2; and this ratio being once determined, each ray must conform itself to it, so that any angle of incidence being given, the direction of the refracted ray may be foretold. Thus, if *i*C be a second ray incident at C, of which *ib* is the sine of the angle of incidence, the ray will be bent into such a course, that *ed* shall be to *ib* as 1 to 2. This ratio is nearly that observed in glass made of one part of flint to three of oxide of lead. In common flint-glass, the ratio is nearly as 1 to 1.6; in water it is as 1 to

1.336; in oil of cassia as 1 to 1.641; in diamond as 1 to 2.755; in phosphorus as 1 to 2.224; and in melted sulphur as 1 to 2.148. By thus representing the sine of the angle of refraction by 1, the sines of the angle of incidence in all bodies refer to the same unit of comparison, and are, therefore, at once comparable with each other; such numbers are called *indices of refraction*, and indicate the degree of refractive power. For example, the *index of refraction* for water is 1.336; for flint-glass 1.6; and for diamond 2.755.

142. *Double Refraction.—Polarization.*—If on a piece of paper with a black line on its surface we place a rhombohedron of Iceland-spar, and then look at the line through the crystal, it will be found that in a certain position the line appears single as when seen through water or glass; but in other positions of the crystal, two lines are visible parallel to each other and separated by a distinct interval. The light in passing through the crystal is divided into two portions, one of which obeys the laws of refraction already explained (142, 143), whereas the other portion proceeds in a wholly different direction, and hence gives the appearance of two objects instead of one. The former is termed the *ordinary*, the latter the *extraordinary* ray. This phenomenon is known by the name of *double refraction*, and has been witnessed in many crystalized substances, as in minerals and artificial salts.

143. Light transmitted through Iceland-spar or other doubly-refracting substance, is found to have suffered a remarkable change. In this state it is distinguished from common light by the circumstance that when it falls upon a plate of glass, at an angle of 56° 11', it is almost completely reflected in one position of the glass, and is hardly reflected at all in another; if reflected when the plane of reflection is vertical, no reflection ensues when the reflecting plane is horizontal, the incident angle being maintained at 56° 11'. This curious property, so different from common light, has been theoretically ascribed to a kind of *polarity* of such sort, that each side of a ray of light is thought to have a character different from the two adjacent sides at right angles to it; and hence the origin of the term *polarized light*, by which this property is distinguished. Light is polarized by reflection from many substances, such as glass, water, air, ebony, mother-of-pearl, and many crystalized substances, provided the light is incident at a certain angle peculiar to each surface, and which is called the *polarizing angle*. Thus the polarizing angle for glass is 56° 11', and for water 53° 14'; that is, common light reflected by glass and water at the angles stated will be polarized.

The phenomena of double refraction and polarized light constitute a department of optics of great and increasing interest; but it is too remote from the pursuits of a chemical student to be treated of at length in this work.

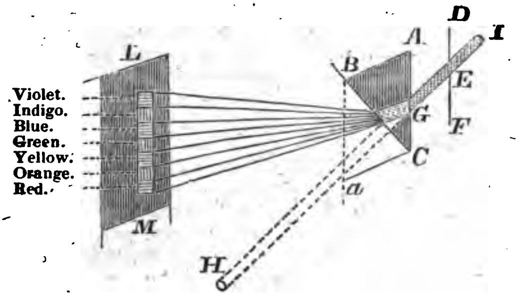
144. It has recently been satisfactorily proved that rays of heat may be polarized in the same manner and by the same means as those of light.

SECTION II.

DECOMPOSITION OF LIGHT.

145. THE analysis of light may be effected either by refraction or absorption. Newton, who discovered the compound nature of solar light, effected its decomposition by refraction, employing a solid piece of glass bounded by three plane surfaces, well known under the name of the *prism.* His mode of operating consisted in admitting a ray of light IG, fig. 16, into a dark chamber through a window-shutter DEF, and interposing the triangular prism ACB, so that the ray should pass obliquely through two surfaces, and be refracted by both. On receiving the refracted ray upon a piece of white paper LM, there appeared, instead of a spot of white light, an oblong colored surface composed of seven different tints, called the *prismatic* or *solar spectrum.* On subjecting each of these colors to refraction, no further separation was accomplished; but on causing the rays separated by one prism to pass through a second of the same power and in an inverted position CBa, the seven colors disappeared, and a spot of white light appeared at H, in the very position which it would have occupied had both prisms been absent. From such and similar experiments Newton inferred that white light is a mixture of seven *colorific* rays,—red, orange, yellow, green, blue, indigo, and violet; and that the separation of these primary or simple rays depends on an original difference of refrangibility, violet being the most refrangible and red the least so.

Fig. 16.



146. Though a prism is the most convenient instrument for decomposing light, the separation of the colored rays is more or less effected by refracting media in general. Lenses, accordingly, disperse the colorific rays at the same time that they

refract them; and this effect constitutes one of the greatest difficulties in the construction of telescopes, insomuch as the separation or *dispersion*, as it is termed, of these rays diminishes the distinctness of the image. The combinations by which the defect is remedied are called *achromatic.*

147. Newton's analysis of light led him to explain the origin of the colors of natural objects. Of opaque bodies, those are black which absorb all the light that falls upon them, and those white which reflect it unchanged; the various combinations of tints are the consequence of certain rays being absorbed, while those alone whose intermixture produces the observed color are reflected. The same applies to transparent media, which are colorless, like pure water, when the light passes through unchanged, but are colored when some rays are transmitted and others absorbed. This absorption of certain rays by colored media, such as glass of different tints, affords another mode of decomposing light; and Brewster has ingeniously applied it to analyze the seven colors which compose the prismatic spectrum. He has proved by such experiments, what has been maintained before, that the seven colors of the spectrum are occasioned not by seven but by three simple or primary rays; namely, the red, yellow, and blue. These rays are concentrated in those parts of the spectrum where each primary color respectively appears; but each spreads more or less over the whole spectrum, the mixture of red and yellow giving orange, of yellow and blue, green, and red with blue and a little yellow causing the violet.

148. The prismatic colors, according to the experiments of Sir W. Herschel, differ in their illuminating power: the orange illuminates in a higher degree than the red, the yellow than the orange. The maximum of illumination lies in the brightest yellow or palest green. The green itself is almost equally bright with the yellow; but beyond the full deep green the illuminating power sensibly decreases. The blue is nearly equal to the red, the indigo is inferior to the blue, and the violet is the lowest on the scale.

149. *Calorific or Heating Rays.*—The solar rays, both direct and diffused, are capable of exciting heat as well as light. When they are transmitted or reflected, no such effect of course results: the concave reflector and burning-glass remain cool, though intense heat is developed at their foci; and the atmosphere is not heated by the solar rays to which it gives passage. But opaque bodies which absorb light are invariably heated by it, and the temperature is proportional to the absorbent power. Hence, dark-colored substances, which are more absorbent than light ones, become hotter when exposed to sunshine. This is indicated by the general preference given to light-colored clothing during summer. Hooke and Franklin, independently of each other, proved the fact, by exposing pieces of cloth of

different colors, but of the same texture and size, upon snow to sunshine; when the snow under the dark specimens was found to melt more freely than under the light ones, the effect being nearly proportional to the depth of shade.

150. For many years it was supposed that the different colored rays possess different heating powers; but different experimenters did not agree with regard to the precise point in the spectrum in which the effect upon the thermometer is greatest, some placing it in the red, and others a little below the red, quite out of the spectrum. It was a question likewise whether light is converted into heat by absorption, or whether heat is only associated with light and absorbed at the same time with it. It has, however, at length been determined that there exists in the solar beam a distinct kind of ray which causes heat and not light; and that this ray being differently refrangible from those of light, the position of the point of greatest heat in the spectrum will depend altogether upon the kind of prism made use of. When the prism used is made of flint-glass, the greatest heat is uniformly beyond the red ray; with a prism of crown-glass the red itself will be the hottest part, but with a prism externally of glass, but containing water within, the greatest heat will be found in the yellow.

151. Our knowledge on this subject has recently been much extended by the able researches of Melloni, who has succeeded with a prism of rock-salt in separating the spot of maximum heat from the colored part of the spectrum by a much greater interval than had been done previously; and showing that, as in simple radiant heat (42), there exist in solar light calorific rays of different characters, some being more, and some less refrangible. He has also shown that the more refrangible rays are less absorbed by feebly transcalent media than the less refrangible ones, while more perfectly transcalent bodies absorb the less refrangible more freely than the more refrangible rays. By causing all the heating rays to be absorbed, he obtained a ray of light that did not in the least affect the most delicate thermo-multiplier, by which it appears that the luminous and calorific rays, as before determined by others, are entirely distinct.

152. *Chemical Rays.*—It has long been known that solar light is capable of producing powerful chemical changes. One of the most striking instances of it, is its power of darkening the white chloride of silver, an effect which takes place slowly in the diffused light of day, but in the course of two or three minutes by exposure to the sunshine. The effect was once attributed to the influence of the luminous rays; but it appears from the observations of Ritter and Wollaston, that it is owing to the presence of certain rays that excite neither heat nor light, and which, from their peculiar agency, are termed *chemical* rays. It is found that the greatest chemical action is exerted just beyond or at the verge of the violet part of the prismatic spectrum; that the spot next in energy is the violet itself; and that the property gradually diminishes in advancing

to the green, beyond which it seems wholly wanting. It hence follows that the chemical rays are still more refrangible than the luminous ones, in consequence of which they are dispersed in part over the blue, indigo, and violet, but in the greatest quantity at the extreme border of the latter.

It appears, therefore, that a beam of light contains three distinct sets of rays, the *illuminating*, the *heating* or calorific, and the *chemical* rays.

153. Many efforts have been made to form permanent image of objects by means of the chemical changes which are produced by light upon different substances, as the white chloride of silver, but till within a few years they seem to have been attended with little success. Recently, however, under the auspices of Talbot and others in England and in this country, and Daguerre in France, *Photography*, or *Photogenic Drawing*, has sprung up as if by magic, and claimed a place among the useful arts.

154. If a piece of white paper is moistened with a dilute solution of common salt, and then one side of it washed with a solution of nitrate of silver, the surface becomes coated with chloride of silver, which readily turns black or dark chestnut, by exposure to the direct rays of the sun. If now before exposing paper thus prepared to the light, any small flat object, as a flower, or piece of lace, be placed upon it, an image of the object will remain upon the paper, and may be rendered permanent by soaking it *immediately* in a saturated solution of common salt, or of iodide of potassium.

Instead of common salt for the first wash, iodide, or bromide of potassium may be used, or chloride of calcium, or indeed almost any substance that is capable of decomposing the nitrate of silver, and forming with the silver a colorless solid compound. Even the salt of silver may it is found be dispensed with; other substances, as the bichromate of potassa, possessing sufficient sensibility to the action of light. But the results, as a matter of course, will be very different according as different substances are used. In every case the process of fixing the picture, consists in washing it in a solution which is capable of dissolving that part of the coloring substance upon which the shadows have fallen, and not that which has been affected by the light.

Paper prepared to be used in this manner is called *photogenic paper*, and must be kept secure from the action of light or the air; and even then it cannot often be long preserved without injury. Scarcely any of it is sufficiently sensitive to be used in the camera obscura.

155. Daguerre's process, which has received the appellation f the *Daguerreotype*, is entirely different, and the results more striking and beautiful. The essential parts of this process are as follows: A piece of silver, or copper plated with silver, and polished with great care, is first to be cleansed with nitric acid and powdered pumice, and exposed a few minutes to the action of vapor of iodine, by which an exceedingly thin coating of iodide of silver is formed upon the surface. The plate is then placed in a camera obscura, and the image of any object in

front is made to fall upon it for several minutes; by which such a chemical change is produced in the thin coating of iodide of silver, that subsequent exposure to the vapor of mercury, at a temperature of from 160° to 165°, brings out a beautiful picture of the object.

Instead of pure iodine, the bromide or chloride of iodine may be used for preparing the plates; but the last compound is said n the whole to be much the best.

The picture when taken from the mercurial process is rendered permanent by removing the coating of iodide of silver, which is readily done by merely pouring over it a warm solution of hyposulphite of soda or of common salt. If while in the solution it is touched at the edge by a piece of clean zinc, the coating is removed almost instantly.

The Daguerreotype process is very simple, but to ensure success, close attention must be paid to various minute particulars, which are fully described in the inventor's original paper.

SECTION III.

TERRESTRIAL LIGHT.

156. UNDER this head it is proposed to include the various kinds of artificial light, which differ so much in several respects from solar light as to require to be made the subject of a separate section. The common method of obtaining such light is by the combustion of inflammable matter, which gives out so much heat that the burning substance is rendered luminous in the act of being burned. All bodies begin to emit light when heat is accumulated within them in great quantity; and the appearance of glowing or shining, which they then assume, is called *incandescence*. The temperature at which solids in general begin to shine in the dark is between 600° and 700°; but they do not appear luminous in broad daylight till they are heated to about 1000°. The color of incandescent bodies varies with the intensity of the heat. The first degree of luminousness is an obscure red. As the heat augments, the redness becomes more and more vivid, till at last it acquires a full red glow. If the temperature still increase, the character of the glow changes, and by degrees it becomes white, shining with increasing brilliancy as the heat augments. Liquids and gases likewise become incandescent when strongly heated; but a very high temperature is required to render a gas luminous, more than is sufficient for heating a solid body even to whiteness. The different kinds of flame, as of the fire, candles, and gas-light, are instances of incandescent gaseous matter.

157. Artificial lights differ in color, and accordingly exhibit

different appearances when transmitted through a prism. The white light of incandescent charcoal, which is the principal source of the light from candles, oils, and the illuminating gases, contains the three primary colorific rays, the red, yellow, and blue. The dazzling light emitted by lime intensely heated, of late so successfully applied for the gas microscope, gives the prismatic colors almost as bright as in the solar spectrum. The light emitted by iron feebly incandescent consists principally of the red rays, as does the red light obtained by means of strontia and lithia; that from ignited boracic acid is such a mixture of the blue and yellow rays as constitutes green; and incandescent soda emits a yellow light, almost wholly free from the rays which cause the red and blue colors.

158. Artificial differs from solar light in containing heat in two states. It contains simple radiant heat like that radiated from a non-luminous body, and which may be separated by transmission through a plate of moderately thick glass; but it also contains other calorific rays associated with the luminous rays, and like them capable of refraction by transparent media. There is reason also for believing that other modifications of heat may be found associated with artificial light, depending upon the nature of the source from which it emanates.

159. The chemical agency of artificial light is analogous to that from the sun. In general the former is too feeble for producing any visible effect; but light of considerable intensity, such as that from ignited lime, darkens chloride of silver, and seems capable of exerting the same chemical agencies as solar light, though in a degree proportionate to its inferior brilliancy.

Phosphorescence.—Light is emitted by some substances, either at common temperatures or at a degree of heat disproportioned to the effect, giving rise to an appearance which is called *phosphorescence.* This is exemplified by a composition termed *Canton's phosphorus,* made by mixing three parts of calcined oyster-shells with one of the flowers of sulphur, and exposing the mixture for an hour to a strong heat in a covered crucible. The same property is possessed by chloride of calcium (Homberg's phosphorus), anhydrous nitrate of lime (Baldwin's phosphorus), some carbonates and sulphates of baryta, strontia, and lime, the diamond, some varieties of fluor-spar called *chlorophane,* apatite, boracic acid, borax, sulphate of potassa, sea-salt, and by many other substances. Scarcely any of these substances, which on account of this peculiar property are called *phosphori,* act unless they have been previously exposed to light: for some, diffused daylight or even lamp-light will suffice; while others require the direct solar light, or the light of an electric discharge. Exposure for a few seconds to sunshine enables Canton's phosphorus to emit light visible in a dark room for several hours afterwards. Warmth increases the intensity of light, or will renew it after it has ceased; but it diminishes the duration. When the phosphorescence has ceased it may be restored, and in general for any number of times, by renewed exposure to sunshine; and the same effect may be produced by passing electric discharges through the phosphorus. Some phosphori, as apatite and chlorophane, do not shine until they are gently heated; and yet if exposed to a red heat, they lose the property so entirely that exposure to solar light does not restore it. It has been remarked that in these minerals the phosphorescence destroyed by heat, is restored by electric discharges; that specimens of fluor spar, not naturally phosphorescent, may be rendered so by electricity; and that this agent exalts the energy of natural phosphori in a very remarkable degree. The theory of these phenomena is very obscure. They have been attributed to direct absorption of light, and its subsequent evolution; but the fact that the color of the light emitted is more dependent on the nature of the phosphorescent body than on the color of the light to which it was exposed, seems inconsistent with this explanation. Chemical action is not connected with the phenomena; for the phosphori shine *in vacuo*, and in gases which do not act on them, and some even under water.

160. Another kind of phosphorescence is observable in some bodies when strongly heated. A piece of lime, for example, heated to a degree which would only make other bodies red, emits a brilliant white light of such intensity that the eye cannot support its impression.

161. A third species of phosphorescence is observed in the bodies of some animals, either in the dead or living state. Some marine animals, and particularly fish, possess it in a remarkable degree. It may be witnessed in the body of the herring, which begins to phosphoresce a day or two after death, and before any visible sign of putrefaction has set in. Sea-water is capable of dissolving the luminous matter; and it is probably from this cause that the waters of the ocean sometimes appear luminous at night when agitated. The appearance is also ascribed to the presence of certain animalcules, which, like the glow-worm or the fire-fly, are naturally phosphorescent.

162. Light sometimes appears during the process of crystalization. This is exemplified by a tepid solution of sulphate of potassa in the act of crystalizing; and it has been likewise witnessed under similar circumstances in a solution of fluoride of sodium and nitrate of strontia. Another instance of the kind is afforded by the sublimation of benzoic acid. Allied to this phenomenon is the phosphorescence which attends the sudden contraction of porous substances. Thus, on decomposing by heat the hydrates of zirconia, peroxide of iron, and green oxide of chromium, the dissipation of the water is followed by a sudden increase of density suited to the changed state of the oxide, and a vivid glow appears at the same instant. The essential conditions are that a substance should be naturally denser after decomposition than it was previously, and that the transition from one mechanical state to the other should be abrupt.

163. Several different instruments have been contrived to measure the comparative intensities of different lights, called *photometers;* but it is thought little reliance can be placed upon any of them. The only one that has been much used is that of Leslie, which consists simply of his differential thermometer (75) with one of its balls made of black glass. The clear ball transmits all the light that falls upon it, and therefore its temperature is not affected; on the contrary, they are all absorbed by the black ball, and, by heating and expanding the air within, cause the liquid to rise in the opposite stem. The action of this instrument, it will be seen, depends not immediately upon the quantity of light that may be absorbed, but upon the heat which accompanies it. The results obtained by it cannot therefore be relied upon.

164. Radiant heat and light possess in many respects so close a resemblance, that a conviction of the near relationship of their origin is forced

upon it. They are distributed, reflected, refracted, absorbed, transmitted, and polarized, according to laws exactly parallel; but though the undulatory theory of light is considered well established, it seems impossible to assign a similar cause to heat, and account satisfactorily for the various relations it sustains to matter, as connected with change of form, specific heat, &c.

CHAPTER III.

ELECTRICITY.

SECTION I.

GENERAL PRINCIPLES.

165. When certain substances, such as amber, glass, sealing-wax, and sulphur, are rubbed with dry silk or cloth, they are found to have acquired a property, not observable in their ordinary state, of causing contiguous light bodies to move towards them; or if the substances so rubbed be light and freely suspended, they will move towards contiguous bodies. After a while this curious phenomenon ceases; but it may be renewed an indefinite number of times by friction. The principle thus called into action is known by the name of *electricity*, from the Greek word ηλεκτρον, amber, because the electric property was first noticed in it. The same term is applied to the science which treats of the phenomena of electricity.

166. When a substance by friction or any other means acquires the property just stated, it is said to be *electrified*, or to be *electrically excited;* and its motion towards other bodies, or of other bodies towards it, is ascribed to a force called *electric attraction*. But its influence, on examination, will be found to be not merely attractive; on the contrary, light substances, after touching the electrified body, will be disposed to *recede* from it just as actively as they approached it before contact. This is termed *electric repulsion*. By aid of the electrical machine these phenomena of electric attraction and repulsion may be displayed by a great variety of amusing and instructive experiments, showing how readily an invisible power is called into operation, and how wonderfully inert matter is subject to its control. But the student may witness these effects quite satisfactorily by very simple apparatus. Let him suspend a thread of white sewing-silk from the back of a chair so that one end may hang freely, taking the precaution to moisten that end slightly by holding it between the fingers, while the rest of

the thread is carefully dried by the fire; and let him then place near the free end a piece of sealing-wax, previously rubbed on the sleeve of his coat. The silk will move towards it; but after touching the excited wax two or three times, it will recede from it.

167. When an electrified body touches another which is not electrified, the electric property is imparted by the former to the latter. Thus, on touching the free end of the suspended silk-thread with the excited wax, the silk will itself be excited, as shown by its moving towards a book, a knife, or other unexcited object placed near it. But, though electricity is always imparted by an excited to an unexcited body by contact, the latter does not always exhibit electric excitement. If, for example, the suspended silk be wetted along its whole length, it will be strongly attracted by the excited wax, but after contact it will not evince the least sign of being itself electrified. Nevertheless, electricity is communicated to the silk in both cases, only it is retained by silk when dry, and is lost as soon as received by wet silk.

168. Such observations led to the discovery that electricity passes with great ease over the surface of some substances, and with difficulty over that of others, and hence the division of bodies into *conductors* and *non-conductors* of electricity. If electricity be imparted to one end of a conductor, such as a copper-wire, the other extremity of which touches the ground, or is held by a person standing on the ground, the electricity will pass along its whole length and escape in an instant, though the wire were several miles long; whereas excited glass and resin, which are non-conductors, may be freely handled without losing any electricity except at the parts actually touched.

169. To the class of conductors belong the metals, charcoal, plumbago, water, and aqueous solutions, and substances generally which are moist or contain water in its liquid state, such as animals and plants, and the surface of the earth. These, however, differ in their conducting power: of the metals, silver and copper are found to be the best conductors, and after these follow gold, zinc, platinum, iron, tin, lead, antimony, and bismuth. Aqueous solutions of acids and salts conduct much better than pure water.

170. To the list of non-conductors belong glass, resins, sulphur, diamond, dried wood, precious stones, earth, and most rocks when quite dry, silk, hair, and wool. Air and gases in general are non-conductors if dry, but act as conductors when saturated with moisture.

It is not, however, to be understood that any very definite line can be drawn between the two classes of conductors and non-conductors, but there seems to be a very regular gradation from the most perfect conductor to the most imperfect or most perfect non-conductor. This division of substances is, however, found very convenient, though in some instances individuals might differ with regard to the class to which a particular substance is to be assigned.

171. This knowledge is of continual application in electrical experiments. When it is wished to collect electricity on a metallic surface, the metal must be *insulated*, that is, cut off from contact with the earth, and with conductors touching the ground, by means of some non-conductor; an object commonly effected either by supporting it on a handle of glass, or by placing it on a stool made with glass feet. Another mode of insulating is to suspend a substance by silk threads. But such insulators must be dry; since they begin to conduct as soon as they grow damp, and conduct well, as in the experiment above described, when wet. Again, electrical experiments are very apt to fail in damp weather, because the moisture both carries off electricity directly, and by being deposited on the glass supports, destroys the insulation.

To diminish this inconvenience it is usual to keep the insulators warm, and to coat them with a varnish made by dissolving the resin called shell-lac in alcohol, this resinous matter being much less prone to attract moisture from the air than glass. The same principles account for an error once prevalent, that a metal cannot be excited by friction: if held in the hand, indeed, it exhibits no sign of excitement when rubbed, because the electricity is carried off as soon as excited; but if, while carefully insulated, it is rubbed with dry cat's fur, excitement readily ensues.

172. On comparing the electric properties manifested by glass and sealing-wax when both are rubbed by a woollen or silk cloth, they will be found essentially different; and it is therefore inferred that there are two kinds or states of electricity, one termed *vitreous*, because developed on glass, and the other *resinous* electricity, from being first noticed on resinous substances. These two kinds of electricity, one or other of which is possessed by every electrified substance, are also termed *positive* and *negative*, the terms *vitreous* and *positive* being used synonymously, as are *resinous* and *negative*; they are also sometimes designated by the signs + and −. The mode of distinguishing between positive and negative electricity is founded on the circumstance that, if two electrified substances are both positive or +, or both negative or −, they are invariably disposed to recede from each other, that is, to exhibit repulsion; but, if one be positive and the other negative, their mutual action is as constantly attractive. The end of a silk thread, after contact with an electrified stick of sealing-wax, is repelled by the wax, because both are negative; but if a dry warm wine-glass be rubbed with cloth or silk, and then presented to the thread, attraction will ensue, as the glass will be

positive. A silk thread in a *known* electric state, thus indicates the kind of electricity possessed by other substances: a convenient mode of doing this is to draw a thread of white silk rapidly through a fold of coarse brown paper, previously warmed, by which means its whole length will be rendered positive.

173. When two substances are rubbed together so as to electrify one of them, the other, if in a state to retain electricity, will be excited also, one being always negative and the other positive. It is easy to be satisfied of this by very simple experiments. Rub a stick of sealing-wax on warm coarse brown paper, and the paper will be found to repel a positively excited thread of silk, while the wax will attract it; if a warm wine-glass be rubbed on the brown paper, the glass will be positive, as shown by its repelling the positive thread, while the same thread will be attracted by the negative paper; friction of sealing-wax on a silk riband renders the wax negative and the riband positive, but with glass the riband is negative. If two silk ribands, one white and the other black, be made quite warm, placed in contact, and then drawn quickly through the closed fingers, they will be found on separation to be highly attractive to each other, the white being positive and the black negative. The back of a cat is positive to all substances with which it has been tried, and smooth glass is positive to all except the back of a cat. Sealing-wax is negative to all the substances just enumerated, but becomes positive by friction with most of the metals. The reader will perceive from these facts that the same substance may acquire both kinds of electricity, becoming positive by friction with one body, and negative with another.

THEORIES OF ELECTRICITY.

174. The nature of electricity is at present involved in obscurity. If really material, it is so light, subtile, and diffusive, that it has hitherto been found impossible to recognize in it the ordinary characteristics of matter; and, therefore, electric phenomena might be referred, not to the agency of a specific substance, but to some property or state of common matter, just as sound is produced by a vibrating medium. But the effects of electricity are so similar to those of a mechanical agent, that its claim to be considered a material substance, has generally been admitted.

175. *Dufay's Theory of Two Fluids.*—This theory, though usually spoken of as Dufay's, originated partly with him and partly with Symmer. It supposes there are two electric fluids which are equally subtile, elastic, and universally diffused, and each highly repulsive to its own particles, but as highly attractive to those of the opposite kind; these attractive and repulsive forces being exactly equal at the same distances.

When a body is in its *natural state*, that is, when it exhibits no signs of electricity, it is supposed these two fluids exist in it in a state of combination so as to neutralize each other; but electrical excitation is produced when either of them is in excess. Their combination is destroyed, of course, by the several causes which produce electrical excitement.

The application of this theory to most electrical phenomena is easy, and it is not necessary here to go into details.

In most cases, when glass or any other vitreous substance is rubbed, the electricity which is collected is the reverse of that obtained when sealing-wax is subjected to friction; and hence the former is called *vitreous* and the latter *resinous* electricity, as before explained (172).

176. *Franklin's Theory of a Single Fluid.*—Franklin's theory is founded upon the supposition that there is but one electric fluid, the particles of which repel each other, but are attracted by the particles of matter in general. Material substance in its unelectric or natural state is regarded as a compound of matter and electricity, saturated and neutralized with each other. Bodies in this state are said to possess their natural quantity of electricity, and are electrically indifferent, being neither attracted nor repelled by each other.

Electrical excitement is occasioned either by increase or diminution of the natural quantity of electricity. On rubbing a tube of glass with a woollen cloth, the electric condition of both is disturbed: the glass acquires more electricity than it naturally possesses, or is over-charged with electric fluid; and the cloth, losing what the glass gains, contains less than its natural supply, or is under-charged. These opposite states are denoted by the algebraic terms *positive* and *negative*, the former corresponding to the vitreous, the latter to the resinous electricity of Dufay, as before intimated.

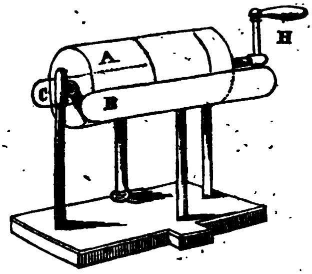
Bodies either positively or negatively electrified repel each other; when positively electrified, in consequence of the repulsion among the particles of the electric fluid with which they are surcharged; but to account for the equal tendency of negatively electrified bodies to separate, it has been contended that a mutual repulsion must be ascribed to the particles of matter itself. This, it was for a long time supposed, could not be admitted, as it appeared to be directly contrary to the well-established law of universal gravitation; but it has recently been shown by Mossotti that this law applies to matter only when in its ordinary state of combination with electricity, and is not inconsistent with the supposition that, deprived of this principle, the particles of matter may be mutually repulsive. Though the theory of Dufay, therefore, has for some time been in the ascendant, it is now believed that all known phenomena admit of explanation equally well upon that of Franklin.

CAUSES OF ELECTRICAL EXCITEMENT.

177. *Friction.*—This cause of electric excitement having been already mentioned, it here only remains to state the usual

modes of developing electricity by friction. A supply of negative electricity is easily obtained by rubbing a stick of sealing-wax or a glass tube covered with sealing-wax, with silk or woollen cloth; and positive electricity is freely developed when a dry glass tube is rubbed with silk, brown paper, or flannel, the surface of which is covered with a little amalgam. But for obtaining an abundant supply of electricity it is necessary to employ an electrical machine, which is a mechanical contrivance for exposing a large surface of glass to continuous friction. As now constructed, it is formed either with a cylinder or plate of glass, which is made to revolve upon an axis, and pressed during rotation by cushions or rubbers made of leather stuffed with flannel, and covered usually with silk. On the rubber is spread an amalgam of tin and zinc, rendered adhesive by admixture with a small quantity of lard or tallow. To prepare the amalgam, melt in a Hessian crucible one ounce of tin and three of zinc, then add two ounces of mercury heated to near its boiling point, stir briskly with a stick for a few minutes, and pour the mixture on a clean dry stone: when cold, pulverize and sift, and preserve the fine powder in a well-corked dry phial. Another essential part of the machine is the *prime conductor*, which is an insulated conductor, placed in such immediate proximity to the revolving glass, that the electric state of the one is instantly imparted to the other.

Fig. 17.



178. Figure 17 is designed to represent the common cylinder electrical machine. A is the cylinder, which is turned by the handle H, and C the prime conductor, supported by an insulating glass pillar on the further side of the cylinder, from which it receives the fluid on points projecting towards it. To the conductor B, the rubber is attached; and from it a silk flap extends over the cylinder to prevent the fluid from being dissipated. This conductor is also insulated, and, with the rubber, becomes negative when the machine is turned. When a supply of positive electricity is required, a chain is used to connect it with the table.

Electricity excited in this manner by the electrical machine is sometimes called *statical electricity*, to distinguish it from *dynamic electricity*, which will be hereafter described under the head of galvanism.

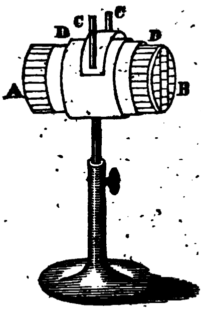
179. The electricity developed by the electrical machine is due partly to friction, which disunites the combined electric fluids of the glass and rubber, but principally to the oxydation

of the amalgam. The positive fluid is transferred to the glass, from it to the contiguous prime conductor, and thence to any system of conductors connected with the prime conductor; and similarly the negative fluid collects upon the rubber, whence it is distributed to one or more conductors with which the rubber may be in connection. Thus all insulated conductors in contact with the prime conductor are positive, and those attached to the rubber are negative, as is shown in fig. 17, by the two pith balls (172) being attracted towards each other. When once the glass and rubber are excited, it is necessary that the electric equilibrium of both should be restored before a second development can occur; and accordingly it is found that very little electricity is obtained when the prime conductor and rubber's conductor are both insulated. To obtain a supply of positive electricity from the prime conductor the rubber must communicate with the ground, in order that its negative electricity may escape. This is usually accomplished by suspending a chain from the rubber to the table on which the instruments stand. In many electrical machines the rubber is not insulated, and then of course the chain is not necessary. To obtain negative electricity from the rubber it must of course be insulated, and the prime conductor must be connected with the ground, so that its positive electricity may escape.

180. *Change of Temperature.*—The operation of this cause of electric excitement was first noticed in certain minerals, such as tourmalin and boracite, the opposite extremities of which, unlike the crystals of most substances, are dissimilar, and are electrified by the application of heat. But a far more general principle was detected by Seebeck, who found that the electric equilibrium is disturbed in certain metallic rods or wires when one extremity has a different temperature from that of the other, whether the difference be effected by the application of heat or cold. This observation has been since shown to be true of all metals. The experiment is usually made by heating or cooling the point of junction of two metallic wires, which are soldered together, but it has been shown that a single metal is sufficient, provided that in different parts of the piece there are differences in its texture and cohesion. This effect is readily produced by casting the metal in such a form that one part can be made to cool more rapidly than another.

181. An instrument of great sensibility to heat, called the *thermo-multiplier*, has been constructed on this principle for measuring slight changes of temperature. It is usually constructed with some forty or fifty small bars of bismuth and antimony, placed parallel beside one another, and forming a prismatic bundle, AB, figure 18, about one and a quarter inch long and three-quarters of an inch in diameter. The bars of bismuth, which are arranged alternately with those of antimony, are soldered at their extremities, and separated all through their length by an insulating substance. To the first and last bars are attached copper wires which termi-

Fig. 18.



nate in the pins CC, of the same metal, passing across the piece of ivory fixed on the ring DD. The free extremities of the wire of a galvanometer (262) are then to be brought in contact with the pins CC, and the needle by its motions indicates any change of temperature which is occasioned among the elements of the pile. The instrument is designed to be sustained by a jointed support, so as to allow freedom of motion in every direction.

Instruments of this kind have been made so sensitive as to indicate a variation of temperature of $\frac{1}{3000}$th of a degree of Fahrenheit's scale.

The experiments of Melloni on the diathermousness of bodies already referred to (40, 42) were performed by an instrument o this kind.

182. *Chemical Action.*—Another, and probably the most fertile source of electricity, is chemical action. This was denied by Davy in his Bakerian lecture for 1826; but experiments afford decisive proof that chemical union and decomposition are both attended with electrical excitement.

It has been demonstrated that the gas arising from the surface of burning charcoal is positive, while the charcoal itself is negative; and that similar phenomena are produced by the combustion of hydrogen, alcohol, oil, and other inflammables of the same kind. In all these instances the combustible, in the act of burning, renders contiguous particles negative; while the oxygen imparts positive electricity to the products of combustion. The fact, with respect to charcoal, was originally noticed by Volta, La Place, and Lavoisier, but was subsequently denied by Saussure and Davy. Pouillet has reconciled these conflicting statements by showing that the result depends on the particular mode in which the experiment is conducted. For if the carbonic acid be completely removed from the burning mass at the instant of its formation, both are found to be electrical; but if the carbonic acid subsequently flow over the surface of the charcoal, the equilibrium will instantly be restored, and no sign whatever of excitement be perceptible.

183. Decisive evidence of the same kind is supplied by the amalgam of the electrical machine, the influence of which is proportional to the degree of chemical action, and which ceases to be useful as soon as the metals are oxydized. Thus, Wollaston found that an amalgam of silver and platinum, which is indisposed to oxydize, is of no use when applied to the rubber; and that an amalgam of zinc and tin, which is the most oxydable, is also the best amalgam for exciting the machine. He observed that a machine in good action ceased to act when surrounded with carbonic acid, but instantly recovered its action on re-admitting the air.

184. *Contact.*—Another reputed source of electricity is contact of different substances, especially of metals; a source originally suggested by Volta, who founded on it a theory of galvanism. Numerous facts have been adduced by later experimenters in proof of the position that mere contact is sufficient to produce electric excitement. Thus, when zinc is brought in contact with copper or silver, and again separated by means of an insulating handle, the zinc is found positive, and the copper or silver, if it has been insulated, negative. If iron, or manganese, or even plumbago, be substituted for the zinc plate, the result will be the same. Other metals may also be substituted for these with the same effect, though in many cases the excitement is exceedingly weak.

185. When oxalic, succinic, benzoic, or boracic acid, either in powder or in crystals, is touched with a plate of copper insulated with a glass handle, the copper becomes positive, and the acids negative. So also phosphoric acid, when applied to copper, becomes negative, and the metal positive. When metallic plates are made to touch dry lime, strontia, baryta, magnesia, or soda, these alkaline bodies become positive and the metal negative; and when sulphur is applied to polished lead or other metal, it becomes positive, the metal taking the opposite state.

These facts rest on too firm a foundation to be shaken; but it is believed that the real cause of the phenomena has been mistaken; and the opinion is daily gaining ground that mere contact is incapable of causing electrical excitation. The effects which have been ascribed by some to this cause are referred by others to chemical action or to friction. The copper and zinc plates, it is found, show no signs of electricity when brought into contact in an atmosphere of nitrogen or hydrogen; and the excitation that is produced in the open air must therefore depend upon the slight oxydation that is then constantly going on even in the driest atmosphere.

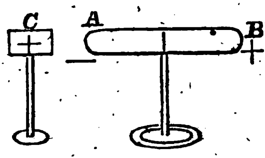
This opinion is farther confirmed by the fact that the electrical effects are much increased by introducing acid fumes into the atmosphere, or using other means to increase the chemical action. In other cases the electrical effects observed may be produced by the friction of the metals or other substances used.

186. *Change of Form.*—The changes of form caused in a substance by variation of temperature, such as liquefaction and solidification, the formation and condensation of vapor, constitute another reputed source of electricity. On liquefying sulphur in a glass vessel, and removing the cake after cooling, the sulphur is found to be negative and the glass positive; and on pouring water into a hot iron vessel or on a hot coal communicating with a delicate electrometer, the rapid evaporation of the water is attended with decisive indications of electrical excitement. To processes of this nature, continually taking place in the atmosphere, the electricity of the clouds is generally ascribed.

This opinion, however, has been questioned, and it has been satisfactorily shown that in most of the experiments adduced in its favor, chemical actions ensue at the same time, and that much of the effect is due to such changes. If, for example, evaporation be accompanied by chemical decomposition, as when saline solutions are evaporated, the water being separated from the salt with which it was previously united, or if the vessel consist of iron or other easy oxydable material, which is more or less chemically attacked by the evaporating water, then the development of electricity is very decisive; but when pure water is evaporated from a platinum vessel, the quantity of electricity excited, it is admitted, is very small. Nevertheless, a small quantity is formed, and very recently it has been found that large sparks of electricity may draw from the steam issuing into the air from a large steam-boiler.

187. *Proximity to an Electrified Body.—Induction.*—It is a direct consequence of the attractive and repulsive powers ascribed to the electric fluids, that an unelectrified conductor must be excited by the vicinity of an electrified body. Thus if an unexcited conductor AB, supported by an insulating glass rod, is brought near another body C charged with positive electricity, as the prime conductor of an electrical machine, the end A immediately shows signs of negative electricity, and B the opposite kind. If the body C had been electrified negatively, the end A of the conductor AB would have become positively electrified and B the reverse. The electricity thus *induced* by the proximity of an electrified body is said to be excited by *induction.*

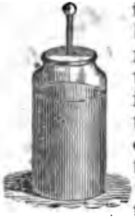
Fig. 19.



188. But the effect thus produced in the body AB, when brought in proximity to the electrified body C, does not depend entirely, as was formerly supposed, upon the greater or less distance of these bodies from each other, but also, as has recently been shown by Faraday, upon the air or other medium interposed between them. He has proved conclusively that different substances, when placed between the electrified body and that on which the electricity is induced, differ essentially in their power to transmit this influence, whatever it may be; and, he proposes to call this property of bodies their *specific inductive capacity.* According to his experiments, the power of air, flint-glass, shell-lac, and sulphur, to transmit this influence, or their several specific inductive capacities, are in the order in which they are mentioned, that of sulphur being more than twice that of air.

189. These facts being established, an inquiry arises with respect to the manner in which the inductive force is propagated from the electrified body to that on which the electricity is induced. In the conduction of electricity, the fluid, whether positive or negative, doubtless is conducted or transferred from particle to particle, through the whole extent of the conducting substance; so also in induction, in the opinion of Faraday, the inductive force is propagated from particle to particle, not however by the fluid passing over them, but by the particles being thrown into a certain polarized state by the electrified body sustaining the action, each assuming positive and negative parts, similarly arranged with respect to each other and to the inducting surfaces.

Fig. 20.



190. The action of the *Leyden Jar* depends on the principle of induced electricity. A glass jar or bottle, fig. 20, with a wide mouth, is coated externally and internally with tin-foil, except to within three or four inches of its summit; and its aperture is closed by dry wood or some imperfect conductor through the centre of which passes a metallic rod communicating with the tin-foil, on the inside of the jar. On placing the metallic rod in contact with the prime conductor (179) of an excited electrical machine, while the outer coating communicates with the ground, the interior of the jar acquires a charge of positive electricity, and the exterior becomes as strongly negative.

The opposite electric fluids accumulated on the opposite sides of a charged Leyden jar exert a strong mutual attraction through the substance of the glass. The exterior of the jar may be freely handled, and its coating removed, without destroying the charge, provided no communication be made at the same time with the interior; and if the exterior be insulated, the charge will be preserved, though the tin-foil of the interior be removed. But when a conductor communicates with both surfaces at the same instant, the two fluids rush together with violence, and the equilibrium is restored.

191. The electric shock, as it is called, is experienced when one hand is made to communicate with the outside and the other with the inside of the jar; the current of electricity, in restoring the equilibrium, of course passing quite across the body.

192. Several instruments called electroscopes or electrometers have been invented to measure the intensity of bodies differently excited, but as this discussion of "general principles" is designed only as preparatory to the following section on Galvanism, no description of them is here given. For a full discussion of the subject of common electricity, the intelligent student is referred to the Library of Useful Knowledge, Olmsted's Philosophy, and other works.

SECTION II.

GALVANISM.

193. The science of Galvanism owes its name and origin to the experiments on animal irritability made by Galvani, professor of anatomy at Bologna, Italy, in the year 1790. In the course of the investigation he discovered the fact that muscular contractions are excited in the leg of a frog recently killed, when two metals, such as zinc and silver, one of which touches

the crural nerve, and the other the muscles to which it is distributed, are brought into contact with one another. Galvani imagined that the phenomena are owing to electricity present in the muscles, and that the metals only serve the purpose of a conductor. He conceived that the animal electricity originates in the brain, is distributed to every part of the system, and resides particularly in the muscles. He was of opinion that the different parts of each muscular fibril are in opposite states of electrical excitement, like the two surfaces of a charged Leyden phial (190), and that contractions take place whenever the electric equilibrium is restored. This he supposed to be effected during life through the medium of the nerves, and to have been produced in his experiments by the intervention of metallic conductors.

194. The views of Galvani had several opponents, one of whom, the celebrated Volta, professor of natural philosophy at Pavia, succeeded in pointing out their fallacy. Volta maintained that electric excitement is due solely to the metals, and that the muscular contractions are occasioned by the electricity thus developed passing along the nerves and muscles of the animal. To the experiments instituted by Volta we are indebted for the first voltaic apparatus, which has properly received the name of the *voltaic pile;* and to the same distinguished philosopher belongs the real merit of laying the foundation of the science of Galvanism.

195. The identity of the agent concerned in the phenomena of galvanism and of the common electrical machine is now a matter of demonstration. Galvanic and common electricity are due to the same force, excited by different conditions, operating in general in a different manner and under different circumstances. The effects of the latter are caused by a comparatively small quantity of electricity brought into a state of insulation, in which state it exerts a high intensity as evinced by its remarkable attractive and repulsive energies, and by its power to force a passage through obstructing media. In galvanism the electric agent is more intimately associated with other substances, is developed in large quantity, but never attains a high tension, and produces its peculiar effects while flowing along conductors in a continuous current.

GALVANIC ARRANGEMENTS OR CIRCLES.

196. Arrangements for exciting galvanism are divided into simple and compound, the former being voltaic circles in their most elementary form, and the latter a collection of simple circles acting together: it will therefore be proper to commence the description of them with the most simple.

197. *Simple Galvanic Circles.*—A simple galvanic circle is formed of three substances, two of which generally are metals, and the other a liquid; but the quantity of the latter may be

very small. The experiment often given to illustrate the original discovery of Galvani is made with a simple circuit. It may easily be performed in the following manner: Separate the legs of a frog from the body, leaving a small portion of the spine with the spinal cord, to which, after removing the skin from the legs, attach a small piece of tin-foil. If now a piece of silver coin or zinc plate is made to touch at the same time the flesh of the thigh and the tin-foil, the muscles of the leg will be instantly convulsed by the passage of the galvanic current; the circle in this case consisting of the two metals and the parts of the animal interposed between them. The irritability will often remain more than an hour, but the experiment should always be made within fifteen or twenty minutes after the frog has been killed.

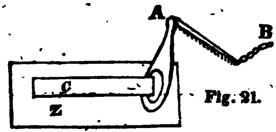


Fig. 21.

198. The legs of grasshoppers[*] answer equally well with those of frogs in performing this experiment, and can be prepared much more readily. It is necessary only to remove with a sharp penknife a portion of the skin from each side of the thick part of one of the leaping legs, so as to expose the flesh; then by laying the under side of the leg upon a small piece of moistened zinc, and bringing a piece of copper in contact with the flesh exposed on the upper side, no motions will be observed until the copper also touches the zinc, when quick movements or jerks of the lower part of the leg will be seen, each time the contact is made. See fig. 21, in which C represents the copper, Z the zinc, and AB the leg of the grasshopper.

199. The following are also examples of the simple galvanic circle, which will perhaps illustrate more clearly what is meant by the term, as well as show some of the different modifications of which it is susceptible.

When a plate of zinc and a plate of copper are placed in a vessel of water, and the two metals are made to touch each other, either directly, or by the intervention of a metallic wire, electricity is excited. The action is, indeed, very feeble, and not to be detected by ordinary methods; but if a little sulphuric acid be added to the water, numerous globules of hydrogen gas will be evolved at the surface of the copper. This phenomenon continues uninterruptedly while metallic contact between the plates continues, in which state the circuit is said to be *closed;* but it ceases when the circuit is broken, that is when metallic contact is interrupted. The hydrogen gas which arises from the copper plate results from water decomposed by the electric current, and its ceasing to appear indicates the moment when the current ceases. In this case the galvanic circle consists of zinc, copper, and interposed dilute acid, and the circle gives rise to a current only when the two metals are in contact. This arrangement is shown in fig. 22, where metallic contact

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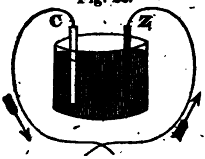
[*] Sil. Journal, xxxi., p. 292.

Fig. 22.

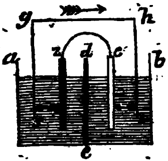


is readily made or broken by means of copper wires soldered to the plates.

The direction of the positive current, it should be remembered, is always *from the zinc through the liquid to the copper*, and in the opposite direction on the wires above the liquid.

It matters not, so far as galvanic action is concerned, at what part the plates touch each other. A current is formed, whether contact between the plates is made below where covered with liquid, above where uncovered, or along the whole length of the plates, provided both plates are immersed in the same vessel of diluted acid.

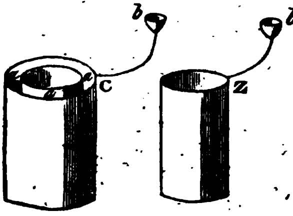
Fig. 23.



But this last condition is absolutely essential, and no current is established where the two plates of metal connected with each other are placed in different vessels, as is *aebe*, figure 23, or are soldered together and made to constitute the separation between two cells in the same vessel, unless the precaution is taken to form a connection with the liquid of the two vessels or cells, by means of some moistened fibres of cotton or other substance, or a metallic wire, as *fghi*, in the figure. In such cases the positive current passes from the zinc vessel or cell, over the conducting substance to the one containing the copper. Figure 23, in the margin, will be understood without more particular explanation. The arrows as before show the direction of the current.

A simple galvanic circle may be formed of one metal and two liquids, provided the liquids are such that a stronger chemical action is induced on one side than on the other. Nay, even a plate of metal with two portions of the same liquid may be made to constitute the simple circuit, provided only the conditions are such that one side of the metal shall be acted upon by the liquid more readily than the other. This will be effected if one portion of the liquid is warmer or stronger than the other, or if one surface of the metal is rough and the other polished.

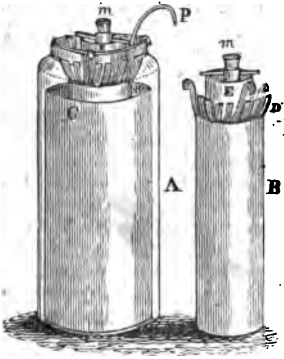
Fig. 24.



200. A very excellent contrivance for a simple circle is made as follows: A copper vessel C, fig. 24, is made of two cylinders of sheet copper of unequal size, placed one within the other, and soldered together at bottom so as to leave an intermediate space *aaa* to contain the zinc cylinder Z and diluted acid, or solution of

blue vitriol, which is found to be better. The small copper cups *bb* are made to contain a little mercury, and are serviceable in enabling the experimenter to close or break the circuit with facility.

Fig. 25.



201. Another modification of the simple circle recently introduced possesses too many advantages to be entirely omitted. A, fig. 25, is a common glass jar of about a quart capacity, containing within it a coil of the thinnest sheet copper, C, supposed to be seen through the glass. Within the copper coil is a cylindrical vessel B, made of calcined plaster, having a piece of copper tube E cemented into it at top, and hemispherical copper vessel D with holes perforated through it like a cullender, or slits, as seen in the figure.

The plaster vessel with its appendages is represented also at the right, removed from the jar. An amalgamated cylinder of zinc is suspended in the plaster vessel by means of a piece of wood which perforates it and rests on the collar of copper. An acid solution of blue vitriol, which is kept saturated by crystals of the salt contained in the cullender D, fills the glass jar around the plaster vessel, which itself contains, surrounding the cylinder of zinc, diluted sulphuric acid, made with one measure of acid and eight of water. A small mercury cup *m* is soldered to the zinc, and a metallic wire P soldered to the coil of copper serves by bending it so as to enter the mercury cup *m*, to close the simple circle (199), or by bending to the right, as in the figure, to connect with the zinc of the next element in the compound circle (208).

202. In this arrangement it will be seen, the cupreous solution comes in contact with the copper only, and the acid only with the zinc. When in action the electric current passes through the sides of the porous plaster vessel, and a deposition of metallic copper is constantly taking place upon the surface of the copper plate.

Animal membrane, as a portion of the gullet of an ox, or a calf's bladder, answers still better than the plaster vessel, but they are difficult to preserve, especially in warm weather.

203. A simple apparatus of this kind, with some slight modifications, constitutes the *electrotype*; which is an invention for copying medals, coins, and other similar articles in copper. When the circle above described is in operation, the sulphate of copper used is gradually decomposed, just as if both the copper and the zinc plates were immersed directly in the blue vitriol solution; but the copper in this case is precipitated in a solid form

(202) upon the copper plate, which is therefore constantly increased in thickness, while sulphate of zinc is formed within the plaster vessel. To use the single circles of this form, therefore, for the purpose of the electrotype, it is only necessary, instead of the copper plate or coil C to have a skeleton or mould of the article to be copied, suspended by a wire or slip of copper and connected with the zinc within the plaster vessel. The mould or pattern should be covered with wax, except the part of it to be copied, upon which the copper will be gradually deposited, copying of course all its minutest peculiarities. It is evident that elevations in the article copied will by this process be represented by depressions, and depressions by elevations, so that a medal in relievo will be copied in intaglio, and vice versa; but to obtain an exact copy in relievo of a medal, it is necessary first to form the intaglio copy, which is to be used as a pattern or matrix in which to cast the copy desired. Sometimes the intaglio copy is made in fusible metal or lead, or even in plaster, but in this last case the surface must be made an electrical conductor by coating it with bronze or washing it with nitrate of silver and exposing it to vapor of solution of phosphorus in alcohol or oil of turpentine.

204. It is not necessary that copper and zinc alone should always be used in these experiments; other metals may be adopted with equal, and, in some cases, even more decisive results. Nor is it required that the liquid should always contain an acid; other substances, as solutions of the salts, are quite as efficacious in exciting this subtile fluid. The conditions required are that the metals and liquid used should be such that chemical action will take place more readily between one of them and the liquid than between the other and the liquid; and that metal is always found positive (below the surface of the liquid) which is most acted upon by it. Other things being equal, the galvanic action will be more intense, the greater the difference between the two metals used, as regards their tendency to be acted on by the particular menstruum in which they are immersed. Thus, with a common acid, silver and zinc would form a more powerful galvanic circle than copper and zinc, and gold or platinum with zinc would answer still better, because copper is more readily acted upon by these acids than either of the other metals mentioned.

205. The current formed by the contact of two metals gives increased effect to the affinity of one of them for some element of the solution, but the ability of the other metal to undergo the same change is proportionally diminished. Thus, when plates of zinc and copper touch each other in dilute acid, the zinc oxydizes more, and the copper less readily than without contact.

It was on this principle that Davy proposed to protect the copper sheathing of ships, by means of pieces of zinc attached to it; but the plan, it is found, cannot be adopted in practice, because the surface of the copper, unless it is gradually corroded by the action of the sea-water, becomes foul and injures the sailing of the ships. The article called *galvanized iron*, recently introduced into use, is simply iron coated with zinc, the latter of which, by the galvanic action that takes place, serves to protect the iron from the rusting that would otherwise be observed.

206. Metallic bodies are not essential to the production of galvanic phenomena. Combinations have been made with layers of charcoal and plumbago, of slices of muscle and brain, and beet-root and wood; but the force of these circles, though accumulated by the union of numerous pairs, is extremely feeble and they are rarely, if ever, employed in practice.

207. Several familiar experiments depend upon the galvanic action that takes place in consequence of the formation of simple galvanic circles. If a piece of zinc, perfectly bright, and a piece of silver be placed, one above the tongue and the other below it, a peculiar taste will be observed every time they are brought in contact with each other.

If a silver dollar be placed upon a larger piece of zinc, an earth-worm or leech placed on the silver will be convulsed by the passage of the electrical current, as often as he extends his body so as to come in contact with the zinc. The worm should be perfectly clean and moist when used.

Iron nails cannot be used in the construction of the bottoms of ships which are to be sheathed with copper, because they are so rapidly corroded in consequence of the galvanic circles which are formed between them and the copper.

208. *Compound Galvanic Circles.*—The compound galvanic circle, or *galvanic battery*, consists of any number of simple circles so arranged in a series that the copper of each simple circle is connected with the zinc of the one adjacent. The first combinations of this kind were described by Volta, and are now well known under the names of the *voltaic pile*, and *couronne des tasses*, or *crown of cups*.* The voltaic pile is formed of pieces of copper, zinc, and cloth, moistened with a saturated solution of salt or acidulated water. Commencing with either of the metals, upon this is placed a piece of cloth and then a piece of the other metal, the three of course constituting a simple galvanic circle. Upon this circle other simple circles are then formed in the same manner, care being taken to place the metals throughout the series in the same order.

Without this precaution the apparatus would give rise to opposite currents, which would neutralize each other more or less according to their relative forces. The pile, which may consist of any number of combinations, should be contained in a frame formed of glass pillars fixed into a piece of thick dry wood, by which it is both supported and insulated. Any number of these piles may be made to act in concert by establishing metallic communication between the positive extremity of each pile and the negative extremity of the pile immediately following.

209. Fig. 26 will assist in forming a correct idea of the voltaic pile, in which the light lines represent the copper, and the

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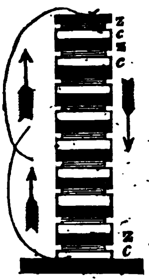
* This name was suggested by the circular form in which he arranged the cups constituting his battery.

Fig. 26.

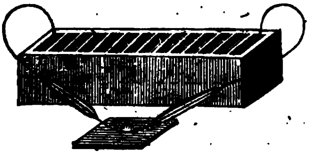


dark lines, the zinc plates, with pieces of moistened cloth, a little smaller than the plates between every pair.

When in action the upper zinc plate is negative and the lower copper plate positive. These extremities of the pile have been called its *poles*, which however may be prolonged by wires, as in the figure. When the poles are united by wires or other conducting substances, a continuous positive current flows from the positive to the negative pole, as indicated by the arrows. Recently it has been proposed to call the poles *electrodes*, from ηλεκτρον, and οδος, a way.

The voltaic pile is now rarely employed, because we possess other modes of forming galvanic combinations which are far more powerful and convenient. The galvanic battery proposed by Cruickshank consists of a trough of baked wood, about thirty inches long, in which are placed at equal distances fifty pairs of zinc and copper plates previously soldered together, and so arranged that the same metal shall always be on the same side. Each pair is fixed in a groove cut in the sides and bottom of the box, the points of junction being made water-tight by cement. The apparatus thus constructed is always ready for use, and is brought into action by filling the cells left between the pairs of plates with some convenient solution, which serves the same purpose as the moistened cloth in the pile of Volta. See fig. 27.

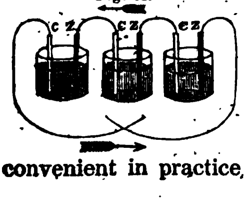
Fig. 27.



Compound circles of this form are yet considerably used in consequence of the great simplicity of their construction, but they have several not unimportant defects, as the liquid used can act only upon one side of each of the plates, nor can it easily be poured at the same instant into all the cells, which is necessary to secure the greatest energy of the instrument.

210. Other modes of combination have been devised to remedy these defects, most of which may be regarded as modifications of the crown of cups of Volta. In this apparatus, which is represented in the figure 28, the exciting solution is contained in separate cups or glasses, disposed circularly or in a line; each glass contains a pair of plates; and each zinc plate is attached to the copper of the next pair by a metallic wire, which is soldered to the plates. Instead of glasses, it is more convenient in practice to employ a trough of baked wood or

Fig. 28.



glazed earthenware, divided into separate cells by partitions of the same material; and in order that the plates may be immersed into and taken out of the liquid conveniently and at the same moment, they are all attached to a bar of dry wood, the necessary connection between the zinc of one cell and the copper of the adjoining one being accomplished by a slip or wire of copper.

211. Still other modifications of the galvanic battery have been proposed, but Faraday, after very numerous experiments, gives the preference to the battery invented some years since by Dr. Hare of Philadelphia, and described by him under the name of the *Galvanic Deflagrator.* In this instrument, the copper plates are made to pass quite around both surfaces of the zinc plates, but are prevented from coming in contact with them by means of little plugs of cork; and the copper plates are separated from each other by the introduction of thin veneers of wood, or pieces of cartridge-paper. The copper and zinc plates are cut out and soldered together, as represented in fig. 29, and are then bent over the gauge, as seen in fig. 30; and when packed in the wooden box constructed to receive them, they are arranged as shown in fig. 31—the zinc plate inclosed in one of the copper cases being soldered to the copper inclosing the next adjacent zinc plate. By this means a great increase of power is obtained. No division of the trough into cells is required.

Fig. 29.

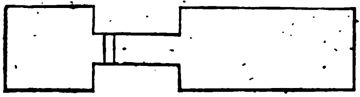


Fig. 30.

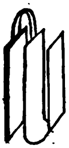
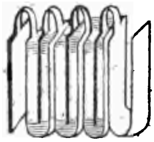


Fig. 31.



212. The size and number of the plates in a battery may be varied at pleasure; but it is found that, except in a very few experiments, little is gained by increasing the number of plates beyond a very moderate limit, a battery of 50 or 100 pairs of plates thrown into vigorous action answering nearly every purpose of one of far greater extent.

The *Calorimotor* of Hare, so named by him from its surprising power of igniting the metals, is composed of 20 zinc and 20 copper plates, each about 18 inches square, so arranged as to constitute two pairs. This instrument, notwithstanding its great heating power, possesses but a very feeble electrical energy, not in any degree superior to that of two pairs of very small plates.

213. A very effective battery which for most purposes it is thought will supersede all others has been formed by Daniel of London, by combining 20 or 25 of the simple circles already described (201, fig. 25). From the constancy of its action it is

called the *constant battery*; and possesses far greater energy than a battery of any other construction with an equal quantity of metal.

214. The electrical condition of compound voltaic arrangements is similar to that of the simple circle. In the broken circuit no electric current can be traced; but in the closed circuit, that is, when the wires from the opposite ends of the battery are in contact, the galvanometer indicates a positive electric current through the battery itself and along the wires, as shown by the arrows in figure 28.

215. As batteries are sometimes constructed, and as they are usually represented in books, the direction of the current appears to be the reverse of that in the simple circuit, but this is in consequence of there being a superfluous plate at each extremity which serves only as a conductor. In the figures in this book, however, these superfluous plates are not represented, and the remarks in the text are made with reference to instruments of this construction.

216. The energy of the battery depends very much upon the nature of the liquid used. A solution of common salt, sulphate of soda, nitrate of potassa, alum, hydrochlorate of ammonia, or other salt will answer the purpose, but acids are much better. Generally one of the stronger acids is used diluted with 20 or 30 times its weight of water. Nitric acid gives the battery the greatest energy, but the action is of short continuance, while hydrochloric acid produces a less intense but more enduring action. Faraday recommends for ordinary purposes a mixture of 4½ parts of sulphuric acid with 4 of nitric diluted with 200 of water. Whatever may be the liquid used, it is of great importance that all the cells of the battery be filled with the same.

217. The electrical column of De Luc is generally classed among galvanic arrangements. As originally contrived it was formed of disks of Dutch gilt paper, alternated with similar disks of laminated zinc. These were piled upon each other in an ordinary dry state; and instead of being soon exhausted, as is the case with other combinations, it continued in active operation for years. A similar pile, it is said, may be formed by laying a mixture of very finely powdered zinc with common glue and a little sugar, by means of a brush, on the back of Dutch gilt paper, and when dry, cutting it in disks, which are to be piled upon each other.

218. This has been quoted as an instance in which electricity is excited by simple contact; but it appears, as the column gives no signs of electricity when made perfectly free from moisture, that something more than the mere contact of the metals is required; and the zinc, it is observed, is gradually oxydized. It is true, the quantity of electricity developed is very large in proportion to the slight oxydation of the metals that takes place, but at the same time it appears to be in the exact ratio of the amount of this oxydation. The action of the column is therefore promoted by any increase in the moisture of the atmosphere, or by elevation of temperature.

Several animals, as the *torpedo*, and the *gymnotus electricus*, have the power of giving powerful shocks of electricity, by means of peculiar galvanic arrangements with which nature has provided them. But it would be out of place here to enter upon a detailed account of these phenomena.

219. *Laws of the Action of Galvanic Circles.*—Electricians distinguish between *quantity* and *intensity* in galvanism as in ordinary electricity. *Quantity*, in reference to a voltaic circle, signifies the quantity of electric fluid set in motion; and by *tension* or *intensity* is meant the energy or effort with which a current is impelled. If two similar conducting surfaces of equal extent be supplied with equal quantities of free electricity, they will possess the same intensity, but if one surface is larger than the other, the intensity of the smaller will be the greatest. Indeed, the intensity will always be in proportion to the quantity of electricity upon a given amount (as a square inch) of surface. We may suppose the degree of intensity to depend upon the smallness of the distance at which the particles are placed from each other. The nearer they are the greater will be the repulsion which they will exercise upon each other, and the greater will be their attraction for the opposite electricity; but the quantity will depend upon the extent of surface over which it is distributed.

A large quantity of electricity requires conductors to be of larger size that the current may be freely transmitted, but currents of high tension are urged forward with greater impetuosity than feeble ones, even of greater quantity, and more readily overcome obstacles interposed to their passage.

220. The current of a single pair of plates, though variable in intensity according as the nature and strength of the exciting liquid varies, never attains a high tension. And even the compound circle, though the pairs of plates be numerous, often fails to acquire a high intensity in consequence of the liquid used being a good conductor and of course affording opportunity for spontaneous discharges. The circle which gives the highest tension is one that excites electricity sufficient for charging the apparatus, while it opposes an obstacle to spontaneous discharges. A battery of numerous small plates excited by water, or a weak saline or acid solution, best answers these conditions.

221. The quantity of electricity circulating in a galvanic battery is exactly the same in all its parts; on the wire which unites the poles, and in the liquid in which the plates are immersed.

It is found to be exactly proportional to the magnetic and chemical effects which it is capable of producing in a manner to be hereafter explained, and hence the quantity of electricity moving through any closed circuit is readily determined either by the deflection which it causes to a magnetic needle, or by its power of chemical decomposition. Where quantity of electricity alone is desired, a single pair of plates is just as useful as a compound circle.

222. By numerous experiments it has been found that the quantity of electricity developed by a single pair of plates is exactly proportional to the surface immersed in the liquid; and, other things being equal, inversely as the square roots of the distance between the plates. If the plates are placed

at a given distance from each other, it will be inversely as the square root of the length of the connecting wire.

It has been shown too that the quantity developed by a compound circle is not increased by increasing the number of plates; a single pair with a good conducting liquid, and supplied with a large connecting wire, produces the same effects in respect to quantity as a battery composed of several pairs of the same size.

223. The quantity of a compound decomposed by a battery is always proportional to the quantity of electricity that passes; but as the compounds exposed to galvanic action are always imperfect conductors, the quantity of electricity that passes will of course depend upon its intensity. Hence chemical decomposition actually depends upon quantity and intensity together.

SECTION III.

EFFECTS OF GALVANISM.

224. The effects capable of being produced by galvanic combinations, may conveniently be divided into three classes, viz., the electrical, chemical, and the magnetic.

Electrical Effects.—These are so called because they are so perfectly analogous to the effects of ordinary electricity. They are best exhibited by the broken circuit, and depend more upon intensity than upon quantity.

225. A Leyden phial may be charged by contact of its inner coating with one wire of the circle, while the outer coating communicates either with the other wire or with the ground. But the charge is always of feeble intensity.

226. On approximating the wires of an active battery, a brilliant spark is seen to pass between them; and on establishing the communication by means of the hands, previously moistened, a distinct shock is perceived. On sending the current through fine metallic wires or slender pieces of plumbago or compact charcoal, these conductors become intensely heated, the wires even of the most refractory metals are fused, and a vivid white light appears at the points of the charcoal, equal if not superior in intensity to that emitted during the burning of phosphorus in oxygen gas; and as this phenomenon takes place in an atmosphere void of oxygen, or even under the surface of water, it manifestly cannot be ascribed to combustion. If the communication be established by metallic leaves, the metals burn with vivid scintillations.

227. In burning metallic-leaf and igniting charcoal, a large quantity of electricity is required of considerably high intensity. The phenomena seem to arise from the current passing along these substances with difficulty; a circumstance which, as they are perfect conductors, can only happen when the quantity to

be transmitted is out of proportion to the extent of surface over which it has to pass, and the intensity must be sufficient to enable the current to pass freely over the interruption in the circuit between the charcoal points, or between the metallic leaves and the opposite pole. To ignite a wire in the closed circle, so high intensity is not necessary.

228. The effects of galvanism above described are so similar to those of the electrical machine, that it is impossible to witness and compare both series of phenomena without ascribing them to the same agent. The question of identity has occupied the attention of different experimenters, and the most satisfactory evidence obtained that both sets of phenomena are to be attributed to the same agent.

These researches have led to a remarkable contrast between the quantity of electricity concerned in the production of voltaic and ordinary electrical phenomena. Faraday states that the quantity of electric fluid employed in decomposing a single grain of water is equal to that of a very powerful flash of lightning; and this statement, surprising as it is, is supported by so strong evidence, that it is difficult to withhold assent to the assertion.

229. *Chemical Effects.*—The chemical effect of galvanism first noticed was in the decomposition of water, which, as we shall hereafter see, is a compound of oxygen and hydrogen, in the ratio by volume of one part of the former to two of the latter.

When two gold or platinum wires are connected with the opposite ends of a battery, and their free extremities are plunged into the same cup of water, but without touching each other, hydrogen gas is disengaged at the negative and oxygen at the positive wire. By collecting the gases in separate tubes as they escape, they are found to be quite pure, and in the exact ratio of two measures of hydrogen to one of oxygen. When wires of a more oxydable metal are employed, the result is somewhat different. The hydrogen gas appears as usual at the negative wire; but the oxygen, instead of escaping, combines with the metal, and converts it into an oxide.

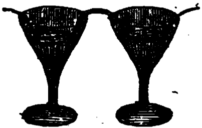
If other compound bodies, such as acids and salts, are exposed to the action of galvanism, they are also decomposed, one of their elements appearing at one side of the battery, and the other at its opposite extremity. An exact uniformity in the circumstances attending the decomposition is also remarked. Thus, in decomposing water or other compounds, the same kind of body is always disengaged at the same side of the battery. The metals, inflammable substances in general, the alkalies, earths, and the oxides of the common metals, are found at the negative wire; while oxygen, chlorine, and the acids, go over to the positive surface.

Those substances which appear at the positive side have been called *electro-negative* bodies, while those that are separated at the negative wire are called *electro-positives*.

The same effect is produced, it is found, even though the solution acted upon is placed in separate cups, provided some fibres of cotton or amianthus are moistened and made to extend from the liquid in one cup to the liquid in the other; one of the ingredients of the compound appearing in one cup and the other in the other.

230. A convenient method of performing the experiment is to place a solution of some salt, as sulphate of soda, in two small glass cups placed side by side, with a few fibres of cotton moistened with the same solution, extending from one to the other. Decomposition of the salt commences at once when the circuit is completed, and the acid is found to be collecting in the cup connected with the positive pole, and the alkali in the other; as will be made evident to the eye by pouring into the cups a little of the blue infusion of red cabbage, which is changed to red by an acid, and green by an alkali.

Fig. 32.



231. It has been asserted farther that the same effect would be produced even though a third cup filled with pure water, or ammonia, or other liquid, were placed between the two cups containing the solution of salt, both the acid and the base passing directly through the intermediate cup without being affected by its contents. The current of electricity on this supposition must not only effect the decomposition of the salt and transfer its elements each to its proper pole, but must also suspend entirely the operation of affinity, so as to enable an acid to pass directly through an alkaline solution, or an alkali through an acid, without combination taking place between them, except in cases when an insoluble compound is formed as with sulphuric acid and baryta.

232. But Faraday has shown that this requires much modification to be in conformity to truth, and that the elements of compound bodies can appear at the opposite poles only when the solution of that body extends quite from one pole to the other. If, for instance, a solution of sulphate of magnesia be carefully covered with pure water, so as to avoid all admixture of particles, and the positive pole touch the magesian solution only, while the negative pole is in contact with the water only, a deposit of magnesia takes place just where the water and the magnesian solution meet, and none reaches the negative pole.

233. Faraday, in revising this part of the science, has introduced a number of terms which it is necessary here to explain. It has already been remarked that the poles he calls electrodes; these are the surfaces of water, air, metal, or any other substance, which serve to convey an electric current into and from the liquid to be decomposed. The surfaces of this liquid which are in immediate contact with the electrodes, and where the elements make their appearance, are termed *anode* and *cathode*, from ανα, *upwards*, and οδος, the way in which the sun rises, and κατα, *downwards*, the way in which the sun sets. The anode is where the positive current is supposed to enter, and the cathode where it quits, the decomposing liquid; its direction, when the electrodes are placed east and

west, corresponding with that of the positive current which is thought to circulate on the surface of the earth, as will be briefly explained on a subsequent page of this work.

234. To *electrolyze* a compound, is to decompose it by the direct action of galvanism, its name being formed from ηλεκτρον and λυω, to *unloose*, or *set free*; and an electrolyte is a compound which may be electrolyzed. The elements of an electrolyte are called *ions*, from the verb ιημι, to go. *Anions* are the ions which appear at the anode, and are usually termed the *electro-negative* ingredients of a compound, such as oxygen, chlorine, and acids; and the *electro-positive* substances, hydrogen, metals, alkalies, which appear at the cathode, are *cations*. Whatever may be thought of the necessity for some of these terms, the words electrode, electrolyze, and electrolyte, are peculiarly appropriate.

235. Contrary to what has been generally supposed, it seems now to be determined that all compound bodies are not electrolytes, that is, are not directly decomposable by an electric current; and those that are capable of decomposition require for this purpose very different degrees of electric force.

236. Some substances however which are not directly decomposable by the current, are decomposed by a secondary action. Thus on subjecting nitric acid to voltaic action, though not an electrolyte, the water contained in it is electrolyzed, and its hydrogen arriving at the negative electrode, decomposes some of the nitric acid, with the formation of nitrous acid. So, in solution of ammonia, the oxygen of the water decomposed unites at the positive electrode with the hydrogen of the ammonia, and nitrogen gas is evolved.

237. Faraday finds there is no such thing as a transfer of ions as was formerly supposed (231); in order that decomposition may take place, it is necessary that the decomposing liquid should extend quite from one electrode to the other, between which the electric current passes. An electrolyte therefore is always a conductor, and decomposition of a liquid always attends conduction. This applies equally to the liquid used in the cells of the battery, which cannot be excited with a liquid that is not an electrolyte.

238. Chemical compounds differ very much in the electrical force required for their decomposition. A current of feeble tension separates the elements of iodide of potassium in solution, while a much higher intensity is required to decompose water.

239. But from what has been said (229, 234), it is not to be inferred that every substance will always make its appearance at the same side of the battery, whatever may be the other body from which it has been separated by the electrolytic action. Oxygen is the only substance that is always separated at the positive electrode; that is, it is always an anion or electro-negative. So potassium is the only substance uniformly obtained at the cathode; that is, it is always a cation or electro-positive.

240. In the following table from Kane's Chemistry, all the well-known simple substances are arranged in the order of their negative-electric energies, beginning at the top of the left-hand column and proceeding down that column, up the second, down the third, and up the fourth. The most

powerfully positive substance will, of course, be found at the top of the last column, and other bodies in the order of their positive electric energies. Any substance in the list therefore is negative with reference to all those that follow it in reading from the left to the right, and positive in relation to those in the opposite direction, or direction in which the arrows point. Thus hydrogen is negative with reference to all the substances in the fourth column, but positive in relation to all in the three preceding columns, except carbon, which stands at the bottom of the third.

Electro-negative.			*Electro-positive.*
Oxygen,	Mercury,	Palladium,	Potassium,
Fluorine,	Chromium,	Silver,	Sodium,
Chlorine,	Vanadium,	Copper,	Lithium,
Bromine,	Iridium,	Lead,	Barium,
Iodine,	Rhodium,	Tin,	Strontium,
Sulphur,	Uranium,	Bismuth,	Calcium,
Selenium,	Osmium,	Cobalt,	Magnesium,
Tellurium,	Platinum,	Nickel,	Glucinum,
Nitrogen,	Titanium,	Iron,	Yttrium,
Phosphorus,	Gold,	Manganese,	Thorium,
Arsenic,	Molybdenum,	Cadmium,	Aluminum,
Antimony,	Tungsten,	Zinc,	Zirconium,
Silicon,	Columbium,	Hydrogen,	Lanthanum,
Boron,		Carbon,	Cerium.

241. *Magnetic Effects.*—The magnetic effects of galvanism are exceedingly interesting and important, and are therefore made the subject of a separate section.

SECTION IV.

ELECTRO MAGNETISM.

In order to be properly prepared for the discussion of Electro-Magnetism, it will be necessary to make a few brief remarks upon the general subject of

MAGNETISM.

242. Among ores of iron, pieces are often found which possess the property of attracting and retaining pieces of iron or steel with more or less force; and are called *magnets* or *loadstone*. These pieces are generally composed of the protoxide and peroxide of iron united in definite proportions, and often mixed with a little silica, alumina, or other substance. Each magnet

always has two points in which the attractive force appears to be concentrated, which are called the *poles*. They are always readily found by rolling the magnet in iron filings, which will be collected more at these points than in other places. Generally they are nearly opposite to each other. If a magnet is broken into several pieces, each always retains the same magnetic properties as the whole mass, but in less degree. Sometimes a magnet has more than two poles.

243. If a magnet be suspended horizontally by a thread, or placed upon a piece of cork floating in a vessel of water, one of the poles will turn towards the north and is hence called the *north pole*, and the other towards the south and is called the *south pole*. Berzelius has proposed to call them *positive* and *negative* poles.

If two magnets thus suspended are brought near each other it will be found that like poles repel each other, but unlike poles attract. These attractions and repulsions extend to some distance, and are not affected by the interposition of other bodies not capable of becoming magnetic.

244. When one of the poles of a magnet is brought in contact with a small piece of soft iron, the iron itself becomes magnetic and remains so while the magnet is in contact with it. Thus when a piece of iron is lifted by a magnet by one end, it will always be found the other end possesses the same polarity as that point of the magnet with which it is in contact, the other end in contact with the magnet of course possessing the opposite polarity. To this piece a second and a third even may be attached, each being rendered magnetic while the contact is maintained. The moment the connection with the first magnet is broken, all signs of magnetism disappear from the pieces of iron.

Fig. 33.

Fig. 33 represents a magnet of steel sustaining a nail, which itself becomes a magnet and sustains a smaller nail, to which a sewing needle is in turn attached in the same manner. Upon removing the magnet, the magnetism in the nails at once disappears.

245. Pieces of steel will also be affected in a similar manner but much less readily, and, unlike iron, they retain the magnetism that has been induced. They therefore become permanently magnetic; and for nearly every purpose are superior to the natural magnet. The same magnet may be used successively to magnetize any number of steel bars without losing any of its virtue, if the bars be not too large; from which it follows that the magnet communicates nothing to them, but only by its influence developes some hidden principle already there. Artificial magnets are frequently made in the form of the horse-shoe, and are called horse-shoe magnets. To the poles

a short piece of soft iron is usually accurately fitted, called the *armature* or *keeper*.

246. A slender bar of magnetized steel suspended upon a pivot so as to revolve freely constitutes the *magnetic needle*. Sometimes it is attached to a circular card and suspended upon a pivot as in the mariner's compass.

247. If a steel bar be suspended by its centre of gravity and afterwards carefully magnetized, it will be found not only to place itself in the magnetic meridian, but to assume a position inclined to the horizon. In northern latitudes the north pole will be depressed and the south pole elevated, while in southern latitudes the south pole will be depressed. The angle of inclination is generally nearly the same in the same place, and is called the *dip of the needle;* and a needle nicely balanced and adjusted for showing the dip is called a *dipping needle*.

248. Other metals, as nickel, cobalt, manganese, and chromium, and even silver and copper, are capable of becoming magnetic but in a less degree than iron or steel. Indeed it has been found that all or nearly all substances are capable of being acted upon by a powerful magnet, so as to indicate feeble polarity.

249. Beside the method pointed out above, magnetism may be communicated to bars of iron and steel by various other means, as by placing them for some time in a perpendicular position,—or better in the position of the dipping needle—by torsion or twisting in a particular manner, by the blow of a hammer, or by pressure, and by the galvanic current, as will be shown hereafter.

250. The earth may be considered as a great natural magnet, which, by its action on the needle in the same manner as any other magnet, causes it to place itself in the position of north and south. Its magnetism will of course be the result of the magnetism of all its parts combined.

251. It has been ascertained that magnetism is also capable of producing certain chemical effects. When a solution of nitrate of silver contained in a syphon tube, with a few grains of metallic mercury, is placed in the direction of the meridian, the silver, it is said, will be precipitated more rapidly than when it is placed in the direction of east and west, and the crystals will be more numerous and more perfect in the northern than in the southern part. When it is placed east and west the silver is precipitated alike in both parts. Murray placed some pieces of iron wire in a weak solution of silver, and no precipitation took place till a magnet was brought near it, which caused the reduction of the metal immediately. These facts will not appear at all surprising when we have discussed the intimate relation between magnetism and electricity.

ELECTRO-MAGNETISM.

252. The power of lightning in destroying and even reversing the poles of a magnet, and in communicating magnetic properties to pieces of iron which did not previously possess them, was noticed at an early period of the science of electri-

city, and led to the supposition that similar effects may be produced by the common electrical and voltaic apparatus. Attempts were accordingly made to communicate the magnetic virtue by means of electricity and galvanism; but no results of importance were obtained till the winter of 1819, when Oersted of Copenhagen made his famous discovery, which forms the basis of a new branch of science.

The fact observed by Oersted was, that the metallic wire of a closed galvanic circle causes a magnetic needle placed near it to deviate from its natural position, and assume a new one, the direction of which depends upon the relative position of the needle and the wire. On placing the wire above the magnet and parallel to it, the pole next the negative end of the battery always moves westward; and when the wire is placed under the needle, the same pole goes towards the east. If the wire is on the same horizontal plane with the needle, no declination whatever takes place; but the magnet shows a disposition to move in a vertical direction, the pole next the negative side of the battery being depressed when the wire is to the west of it, and elevated when it is placed on the east side.

253. Ampère has suggested a useful aid for recollecting the direction of these movements. Let the observer regard himself as the conductor, and suppose a positive electric current to pass from his head towards his feet, in a direction parallel to a magnet; then its north pole in front of him will move to his right side, and its south pole to his left. The plane in which the magnet moves is always parallel to the plane in which the observer supposes himself to be placed. If the plane of his chest is horizontal, the plane of the magnet's motion will be horizontal; but if he lie on either side of the horizontally suspended magnet, his face being towards it, the plane of his chest will be vertical, and the magnet will tend to move in a vertical plane.

254. The extent of the declination occasioned by a voltaic circle depends upon the quantity of electricity in motion, and the distance of the connecting wire from the needle. The declination may amount to 45°; but this does not give an exact idea of the real effect which may be produced by galvanism; for the motion of the magnetic needle is counteracted by the magnetism of the earth. When the influence of this power is destroyed by means of another magnet, the needle will place itself directly across the connecting wire; so that the real tendency of a magnet is to stand at right angles to an electric current.

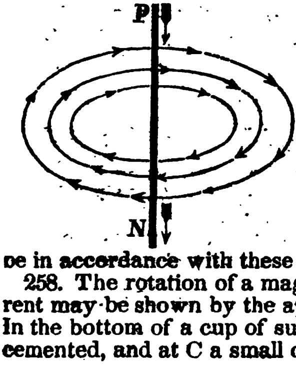
255. The communicating wire is also capable of attracting and repelling the poles of a magnet. This is easily demonstrated by permitting a horizontally suspended magnet to assume the direction of north and south, and placing near it the conducting wire of a closed circle, held vertically and at

right angles to the needle, the positive current being supposed to flow from below upwards. When the wire is exactly intermediate between the magnetic poles, no effect is observed; on moving the wire nearly midway towards the north pole, that is, to the pole which points to the north, the needle will be attracted; and repulsion will ensue when the wire is moved close to the north pole itself. Similar effects occur on advancing the wire towards the south pole. Such are the phenomena if the positive current ascend on the west side of the needle; but they are reversed when the wire is placed vertically on the east side. Attractions and repulsions likewise take place in a dipping needle, when the current flows horizontally across it.

256. By a careful inspection of the motions of the needle above described, in the different positions of the conducting wire, it will be seen that the tendency of each pole is to revolve around the wire, but in opposite directions. The magnetic force which emanates from the conducting wire is evidently exerted in a plane perpendicular to the wire, and tends to produce motion in a circular direction all around it: that is, a direction at right angles to the radius, or in the direction of the tangent of a circle described around the wire, in a plane perpendicular to it. It is therefore very properly called a *tangential force.*

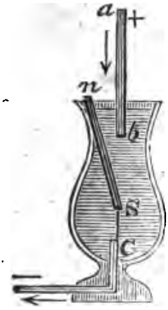
257. The direction in the circumference of these circles, of the action exerted on either pole of a magnet by the electrical current moving at right angles to the plane of the circles, is determined by the direction of the current. If we suppose the conducting wire to be placed in a vertical position, and the current of positive electricity to be descending through it, the tendency of a north pole in the vicinity of the wire will be to move around it in a horizontal circle, in the direction as indicated by the arrows in fig. 34, or in the direction of the hands of a watch with the dial upward. The tendency of the south pole would be to revolve in the opposite direction. If the direction of the electrical current is reversed and made to pass upward, both poles would tend to revolve in the opposite direction from that described above. Whatever may be the position of the conducting wire with reference to the needle, the motions produced will always be in accordance with these principles.

Fig. 34.



258. The rotation of a magnetic pole around the electric current may be shown by the apparatus represented by figure 35. In the bottom of a cup of sufficient depth a copper wire C*d*, is cemented, and at C a small cylindric magnet S*n* is attached by

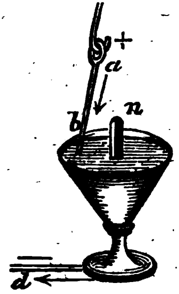
Fig. 35.



a thread; and the cup is filled with mercury A conductor *ab* is then fixed perpendicularly over the mercury, with its lower end dipping into it. If now the positive current is made to descend through the cup of mercury, the north pole *n* will revolve around the current in the direction pointed out above.

259. It requires no reflection to perceive that, if the pole of a magnetic needle tends to revolve around a fixed conducting wire, a free wire will have a tendency to revolve around the pole of a fixed needle. Thus let *n*, figure 36, be the north pole of a fixed needle standing in a cup of mercury, and having a conducting wire *d* cemented in the bottom. The part *ab* of the conducting wire above the mercury and dipping in it is moveable, and revolves around the pole when the electric current is passed through it. Its direction is always the same as that of the pole would be were that moveable and the wire fixed.

Fig 36.

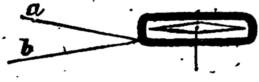


260. The phenomena of electro-dynamics are solely produced by electricity in motion. Accumulated electricity giving rise to tension, which acts so essential a part in experiments with the electrical machine, has no influence whatever on a magnetic needle. The passage of electricity through solid or liquid conductors is essential; and it is remarkable that the more freely the current is transmitted, that is, the more perfect the conducting substance, the more energetic is its deflecting power.

261. Hence the best form of the battery for producing the magnetic effects, as before suggested, is that with a few pairs of large plates, or such as will produce a large quantity (219) of electricity without any reference to its intensity.

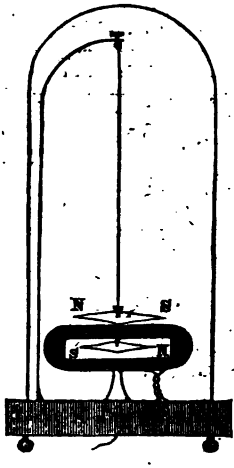
262. But a magnetic needle will not only indicate the existence and direction of an electric current: it may serve, by the degree of deflection, as an exact measure of its force. When used for this purpose, under the name of *Galvanometer*, some peculiar arrangements are required in order to insure the requisite delicacy and precision. Experiment proves that a magnet is equally affected by every point of a conductor along which an electric current is passing, so that a wire transmitting the same current will act with more or less energy, according as the number of its parts contiguous to the needle is made to vary. On this principle is constructed the *Galvanometer* or *Multiplier* of Schweigger. A copper wire is bent into a rectan-

Fig. 37.



gular form consisting of several coils, and in the centre of the rectangle is placed a delicately suspended needle, as shown in fig. 37. Each coil adds its influence to that of the others; and as the current, in its progress along the wire, passes repeatedly above and below the needle in opposite directions, their joint action is the same. In order to prevent the electricity from passing laterally from one coil to another in contact with it, the wire should be covered with silk. The ends of the wire, *a* and *b*, are left free for the purpose of communication with the opposite ends of the voltaic circle. When a single needle is employed, as shown in the figure, its movements are influenced partly by the earth's magnetism, and partly by the electric current. The indications are much more delicate when the needle is rendered *astatic*, that is, when its directive property is destroyed by the proximity of another needle of equal magnetic intensity, fixed parallel to it, and in a reversed position, each needle having its north pole adjacent to the south pole of the other: in this state, the needles, neutralizing each other, are unaffected by the magnetism of the earth, while they are still subject to the influence of galvanism. If, as in figure 38, the lower needle lie within the rectangle, and the upper needle just above it, the electric current flowing between them will act on both in the same manner. For researches of great delicacy, many precautions are necessary, which it is not important here to notice.

Fig. 38.



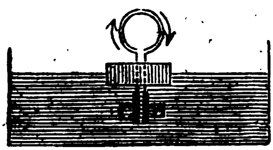
263. The mutual influence of a magnetic pole and a conducting wire, changes with the distance between them; and experiment leads to the conclusion that the attraction of a magnetic pole on a *single* point of a conductor varies inversely as the square of the distance; the same law which regulates the distribution of heat and light.

264. As might be expected, the wire which connects the poles of the battery, while the current is passing, becomes itself magnetic, as may readily be shown by bringing it in contact with iron filings. Indeed, all the attractions and repulsions of the needle by the electric current, may be explained upon the supposition that this current acts upon it in precisely the same manner as another magnet. Hence the wire possessing polarity ought to be influenced by the earth's magnetism, and, if made to revolve properly, ought to settle in a uniform position

with respect to the magnetic meridian, as it actually does. But in order that the effect may be perceptible, it is necessary that a coil or helix of the wire should be formed, so that as many points as possible should be affected by the earth's magnetism in a similar manner, or be urged in the same direction.

This may be shown by an elegant apparatus of De la Rive, which consists of a circular copper wire, the extremities of which are passed through a cork, and soldered to a plate of zinc and copper. On placing the arrangement in a vessel of acidulated water, a positive electric current passes from the copper plate around the circle to the zinc, as shown in fig. 39; and as the cork renders the apparatus buoyant, a very slight force will throw it into motion. It will therefore readily arrange itself at right angles to the magnetic meridian, and on presenting near it either pole of a magnet, it will exhibit various phenomena of attraction and repulsion, all explicable on the principles already explained. We may, therefore, properly regard it as a flat magnet having its two poles in the centre of it, the one on one side, and the other on the other; the *south pole* being in that surface on which, when held before you, the positive current flows in the direction of the hands of a watch. The apparatus will be more powerful if the conducting wire, covered with silk, to prevent lateral communication, be formed into several circles of the same diameter, on the principle of the multiplier.

Fig. 39.



265. The same effect is produced if the wire is wound in the manner represented in figure 40, being supported by the two ends resting in cups of mercury, and the electric current thus made to pass through it.

But it is not necessary that the different coils of the wire should lie in the same plane, the result being the same if it is wound in the form of a helix, as represented in fig. 41, the poles in this case being developed at the extremities of the helix.

Fig. 40.

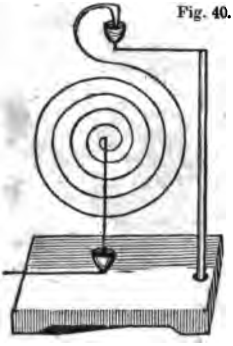
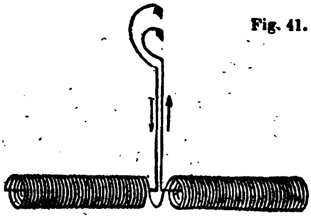
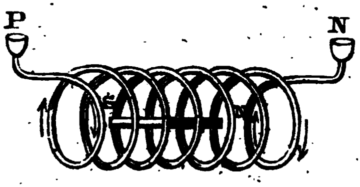


Fig. 41.



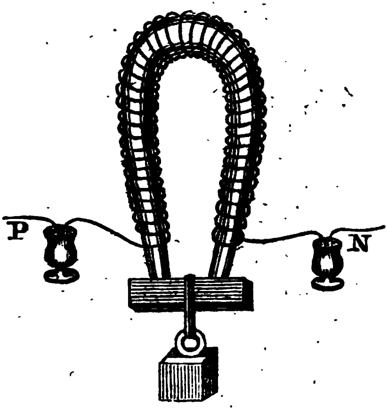
266. A current of voltaic electricity not only determines the position of a magnet, but also induces magnetism in pieces of iron or steel which are brought within its influence. The pieces of iron, upon being removed from the influence of the current, at once lose their magnetism, but those of steel become permanently magnetic; just as in the case of pieces of iron and steel in which magnetism has been induced by an ordinary magnet, as above described (245). This was observed nearly at the same time by Arago and Davy, who found that when needles are placed at right angles to the conducting wire, permanent magnetism is communicated; and Davy also succeeded in producing this effect even with a shock of electricity from a Leyden phial. If the conducting wire is made in the form of a helix, as in figure 42, into the axis of which the piece of iron or steel to be magnetized may be placed, the current in every part of its course is nearly at right angles to it; and, as each coil adds its effect to that of the others, the united action is exceedingly powerful. In this manner a small needle of steel may be fully magnetized in an instant.

Fig. 42.



267. Though soft iron does not retain magnetism, its magnetic properties while under the influence of an electric current are very surprising. A piece of soft iron about a foot long and an inch in diameter is bent into the form of a horse-shoe, a copper wire is twisted around the bar at right angles to its axis, and an armature of soft iron, to which a weight may be attached, is fitted to its extremities, as in fig. 43. On connecting the ends of the wire with a simple voltaic circle, even of small size, the soft iron instantly becomes a powerful magnet, and will support a weight of many pounds. Increasing the number of coils gives a great increase of power; but as the length of wire required for that purpose diminishes the influ-

Fig. 43.



ence of the current (222), the following arrangement, first suggested by Professor Henry, of Princeton College, New Jersey, has been adopted with distinguished success.—*Sil. Journal*, xix. 400, and xx. 201.

268. The total length of copper wire intended to be used is cut into several portions, each of which, covered with silk or cotton thread to prevent lateral communication, is coiled separately on the iron. The ends of all the wires are then collected into two separate parcels, and are made to communicate with the same battery, taking care that the positive current shall pass along each wire in the same direction. The current is thus divided into a number of branches, and has only a short passage from one end of the battery to the other, though it gives energy to a multitude of coils.

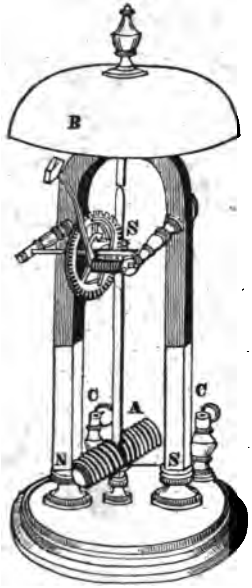
269. To complete the analogy between the electric current and the magnet, it is found that two parallel wires, on which the current flows in the same direction, attract each other, but repel when they flow in opposite directions.

Considerable interest has been excited within a few years, by several attempts to make use of electro-magnetism as a motive power to propel machinery. Prof. J. Henry, it is believed, first constructed an instrument of this kind, capable of producing rotary motion; but *electro-magnetic engines* of various forms have since been contrived by different individuals.

270. The construction of a machine of this kind is exceedingly simple, two magnets only being necessary, one of which must be stationary, and so placed that its poles shall be diametrically opposite to each other, and lie just outside of the circumference of the circle traced by the poles of the revolving magnet, which is supposed to be supported by a movable axis in its centre. Now as the polarity of the magnet depends upon the direction in which the current is sent around the conducting wire which encircles it (264), and can therefore easily be reversed, it is only necessary to adjust the apparatus in such a manner that this effect shall be produced in one of the magnets, just as the poles of the revolving magnet approach nearest those of the stationary one. Being attracted by the influence of unlike poles (243), it will of course now be urged on by the repulsion of like poles; and the same circumstances will constantly be repeated twice each revolution, the poles being each revolution twice reversed.

271. It is not necessary that both should be electro-magnets: one of them may be a common magnetized steel bar, having its polarity, as a matter of course, permanent. Figure 44 represents a very simple electro-magnetic machine, which by its motion rings a bell with considerable force. NS are the north and south poles of a common horse-shoe magnet (245), which stands in a vertical position, with its poles downward. A is a piece of soft iron wound with copper wire and fixed upon a vertical axis, so as to revolve very accurately between the poles of the magnet; and CC are sockets for connecting the wires from the galvanic battery. The extremities of the wire around the magnet A connect with CC, by means of parts not represented in the figure, in such a manner that the current flows in the proper direction to develope north polarity in the further extremity A as it ap-

Fig. 44.



proaches the south pole of the magnet S, and south polarity in the other extremity as it approaches the north pole N; but the moment the revolving magnet has arrived at a position between NS, the two poles of the stationary magnet, where it would of course be held if the same polarity remained, the direction of the current is reversed, and as a necessary consequence the polarity of the revolving magnet. If its momentum has now carried it a little beyond the point of greatest attraction, it will be urged on by repulsion until it has made a quarter of a revolution, when it will be attracted as before. At S on the vertical axis is a perpetual screw which acts upon the teeth of a ratchet wheel, and causes the hammer to strike the bell B.

More than two magnets are generally used, usually at least two stationary and two revolving ones, but then each of the revolving or stationary magnets must have its polarity reversed four times every revolution. It is usual to change the polarity of the revolving magnets only, while that of the others remains permanent.

Whether this ingenious machine will ever be made of any practical utility, remains yet to be determined; but it is said that a boat capable of conveying eighteen men has been propelled by an electro-magnetic engine on the Baltic, at the rate of some three or three and a half miles an hour.

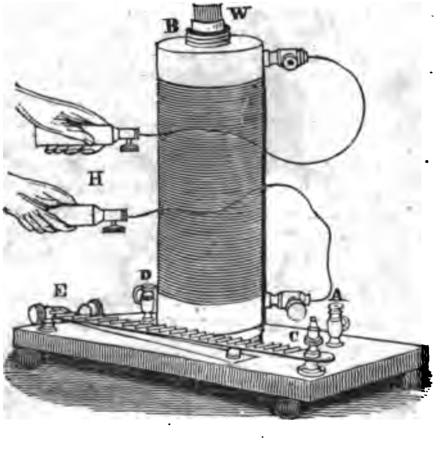
272. Any one who has studied the few preceding pages, cannot fail to trace a close analogy between a helix traversed by an electric current and a magnet. The former is affected by other galvanic conductors, by the poles of a magnet, and by the magnetism of the earth, in the same manner as the latter. It was this similarity, or rather identity of action, which led Ampère to his theory of magnetism. He supposes that the polarity of every magnet is solely owing to the circulation, within its substance and at its surface, of electric currents, which continually pass around all its particles in planes perpendicular to its axis. On placing a magnet in its natural position of north and south, the direction of its currents will be descending on the east side, passing under the magnet from east to west, and ascending on the west side.

If we suppose the magnet placed before us standing perpendicularly upon its north pole, and of course having its south pole upward, the positive electric current is supposed to move in the direction of the hands of a watch, forming a striking agreement with what has been said of the polarity of the spiral or helix (264).

273. In like manner are currents supposed to circulate within the earth especially near its surface, passing from east to west in planes parallel to the magnetic equator. These terrestrial currents cause all bodies, which are freely suspended, and are possessed of electric currents, to place themselves in such a position that the current on their under side should flow in parallelism, and in the same direction, with that in the earth immediately beneath. That the existence of such currents will account for the directive property of the earth, follows from the mutual action of conductors; and Barlow, to render the analogy still more complete, constructed a hollow sphere of wood, in which electric currents were made to circulate in the same direction as they are thought to do in the earth; and by placing an astatic needle on different parts of its surface, he found that all the phenomena of terrestrial magnetism might be imitated. Observation has even supplied a cause for the existence of currents in the earth, moving in the direction which theory requires. The diurnal rotation of our planet on its axis, exposes its surface to be heated in a direction passing from east to west: and discoveries which have been made in thermo-electricity (180), sufficiently prove the probability of electric currents being established in the conducting matter of the earth by the successive heating of its parts. In short, the theory of Ampère connects the facts of electro-dynamics with the phenomena of terrestrial magnetism, and affords a splendid instance of the application of mathematical analysis to physical research.

274. We have heretofore seen (187) that the electric fluid accumulated and at rest in a body induces electricity in another body brought in its vicinity; and it has been determined also that a current of electricity, passing through a helix, is capable of inducing another current in a second helix contained within or surrounding the first. But it is to be observed that this induced current is produced only at the beginning or ceasing of the inducing current; in the former case the direction of the induced is opposite to, but in the latter it is the same as that of the inducing current. This has been called *volta-electric induction.*

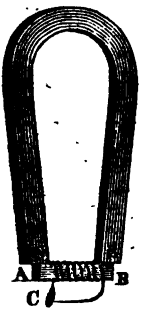
Fig. 45.



A very simple apparatus, to illustrate volta-electric induction is represented in figure 45. Externally a large coil of fine copper wire is seen, terminating in sockets, to which wires with handles H are attached, to be grasped by the hands. Within this is a smaller coil of larger wire, the top of which is seen at B; the extremities of this wire are soldered to the sockets A and D, the latter also connecting with the horizontal bar EC, which has an irregular surface, resembling that of a coarse file. Now when the wires from a galvanic battery are inserted in the sockets, a current at once circulates in the inner helix or coil, which, at the moment of forming or breaking the circle, induces a strong current in the outer one, as may be determined by grasping the handles, or by the galvanometer. In order to break the current from the battery more readily, one of the wires may be attached to A, and the other drawn over the rough surface EC. The use of the part W will be explained in the next paragraph (275).

275. *Magneto-Electricity.*—Magneto-electricity, as the term implies, is the reverse of electro-magnetism. The current of galvanic electricity circulating around a bar of soft iron, converts it, as we have seen (266), into a temporary magnet, and renders a bar of steel permanently magnetic. Now, *a priori*, it would seem very probable that a magnet placed in the centre of a helix or spiral of metallic wire, would develope in it a current of electricity. This is found to be actually the case; but the current can be observed only at the moment of inserting the magnet or removing it (274). Thus it appears that, while magnetism may be induced by an electric current, electricity may also be induced in a wire by a magnet.

Fig. 46.



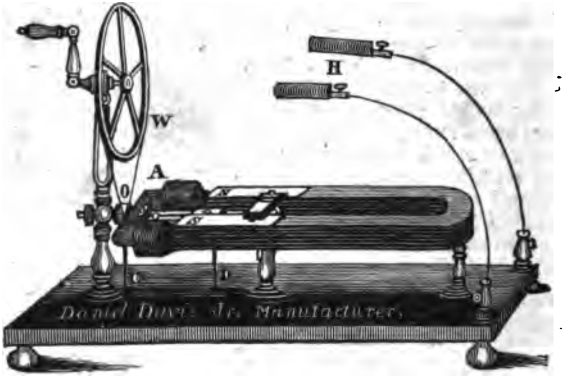
The development of electricity by magnetism is shown in a very simple manner, by winding the middle of the keeper or armature AB, fig. 46, of a powerful horse-shoe magnet with copper wire properly bound, and bringing the two extremities of the wire into contact, one of which should be flattened a little and amalgamated by dipping it into a solution of nitrate of mercury, and the other filed to a point. If now the armature be suddenly placed upon the magnet or removed from it, a spark of electricity will manifest itself every time, at the point of contact C of the two extremities of the wire.

It matters not whether the magnet used is a permanent one, or an electro-magnet. The electro-magnet, as we have seen, consists simply of a piece of iron surrounded by a helix of copper wire, around which the electric current is made to pass. But if this is surrounded with a second helix, a current of electricity will be induced in it by the inclosed magnet, every time a current from the battery is made to pass through the first helix. Indeed, two induced currents make their appearance in the outer helix each time the inner one is connected with the battery; one moving in one direction when the current is formed, and a second in the opposite direction when it is broken.

In the apparatus represented in fig. 45, as described above (274), the current from the battery is made to circulate in the inner coil, by which a secondary current is induced in the outer one; but the intensity of this current is much greater if a bunch of small wires of soft iron W is placed within the inner coil. In the first instance a current is induced by a current, but in this case the wires are magnetized, and by their influence induce the current in the outer coil.

276. Magneto-electric machines are constructed by the use of permanent magnets, either by causing the magnets to revolve, or the armature, generally the latter. Fig. 47* represents a machine of this kind, constructed by Mr. D. Davis, Jr. of Boston. NS are the north and south poles of several powerful magnets placed horizontally upon supports and held firmly in their places. A is an armature of soft iron, bent twice at right angles, and supported upon an axis fixed between the poles of the magnets, so that it revolves before them by means of the multiplying wheel W. The armature is wound with fine copper wire, one end of which is soldered to the armature itself, by which it communicates with the axis and breakpiece seen at O; the other end is attached to a ferule of silver, which is fixed upon the axis but is insulated from it. It is not represented in the figure, but is in contact with the wire D, which communicates, by means of a wire concealed from view, with one of the handles H, the other handle in the same manner connecting with the wire C, which presses upon the breakpiece. The handles therefore may be considered as the extremities of the wire which is wound upon the armature.

Fig. 47.



Now when the armature is set in motion by the multiplying-wheel, its magnetic state is continually changing. When the two extremities of the armature are midway between the poles of the magnet, the armature is neutral. As they advance towards the poles, they acquire a gradually increasing polarity, which is at its maximum when they are opposite the poles; as they pass this point the polarity gradually diminishes till the extremities of the armature are again midway between the poles, when it becomes neutral as before.

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* For this figure as well as for figures 44 and 45, I am indebted to the kindness of Mr. D. Davis, Jr., the well-known manufacturer of philosophical instruments, of Boston, for whose forthcoming work on magnetism and electricity they were prepared. As I have not seen his descriptions, I may not have made precisely the same use of them for which they were intended. In two of them, a little alteration has been made.

As the polarity of the armature is constantly increasing or diminishing when in motion, it is evident a current of electricity (275) will constantly be developed in the wire which envelopes the armature, and this electricity will pass between the breakpiece and ferule by means of the wires connecting them, except when it is interrupted by the wire C slipping from tooth to tooth on the break-piece. A person, therefore, grasping the handles H, at each of these interruptions, will perceive a shock of electricity which, though of itself but slight, will be so rapidly repeated by even moderately turning the machine as to become intolerable.

Intimately associated with magneto-electric induction, if not referable to the same origin, is the induction of electric currents by movement. On introducing a magnet suddenly into a helix of copper wire, or withdrawing it, a current of electricity is momentarily induced; and the same effect is produced if the magnet is stationary and the helix is suddenly moved in its vicinity. The direction of the movement is not material, nor is a copper wire indispensable; but any good electrical conductor will answer the purpose. Indeed, the general principle has been determined, that, if a substance conducting galvanic electricity, produce on magnets (252), or other conductors (259), certain movements, then the battery being removed, and the ends of the conductor brought together, and the same motions produced by mechanical means, the conductor will have the same electric state induced as it had when connected with the battery.

SECTION V.

THEORIES OF GALVANISM.

277. *Theories of Galvanism.*—Of the theories proposed to account for the development of electricity in voltaic combinations, three in particular have attracted the notice of philosophers. The first originated with Volta, who conceived that electricity is set in motion, and the supply kept up, solely by contact or communication between the metals (193). He regarded the interposed solutions merely as conductors, by means of which the electricity developed by each pair of plates is conveyed from one part of the apparatus to the other. Thus having constructed the pile by pairs of zinc and copper plates, as represented by the following series,

$$+\overbrace{\text{zinc . copper}}^{3}\ \text{fluid}\ \overbrace{\text{zinc copper}}^{2}\ \text{fluid}\ \overbrace{\text{zinc copper}}^{1}—$$

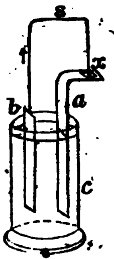
he considered that contact between the metals occasions the zinc in each pair to be positive, and the corresponding copper plate to be negative; that the positive zinc in each pair except the last, being separated by an intervening stratum of liquid from the negative copper of the following pair, yields to it its excess of electricity; and in this way each zinc plate communicates, not only the electricity developed by its own contact with copper, but also that which it had received from the pair of plates immediately before it. Thus, in the three pairs of plates contained in brackets, the second pair receives electricity from the first only, while the third pair draws a supply from the first and second. Hence electricity is most freely accumulated at one end of the battery, and is proportionally deficient at the opposite extremity. But it is now well known that, in the pile as thus constructed, the two extreme plates are entirely superfluous, as they serve only as conductors to the current, and contribute nothing to the result (215).

278. The second is the *chemical theory* of Wollaston, who observed that chemical action is a constant attendant upon the production of galvanic phenomena; and was therefore led to assign this as the cause of the excitement. He observed, further, that no sensible effects are produced by combinations of substances which do not act chemically on each other; that during the action of the pile the zinc is always oxydized, and that its energy is usually proportional to the activity with which its plates are corroded. He therefore concluded that the process begins with the oxydation of the zinc,—that oxydation, or in other terms, chemical action, is the primary cause of the development of electricity,—that the fluid of the circle serves both to oxydize the zinc and to conduct the electricity which is excited,—and that contact between the plates serves only to conduct electricity, and thereby complete the circuit.

279. The third theory of the pile was proposed by Davy, and is intermediate between the two former. It supposes that electric excitement is often, if not always, begun by the simple contact of the metals, but that it is maintained by chemical action.

280. The progress of inquiry since these theories first came into notice, has gradually given more and more support to the views of Wollaston, and has at last, it is believed, established them, to the entire exclusion of any other theory. The very fundamental position that electricity is excitable as a primary result by the mere contact of different substances, is warmly contested, and, as many think, has been disproved (185); but admitting, for the sake of argument, that a *small* effect, which is all that can now be contended for, may be produced by mere contact, it is altogether insignificant when contrasted with the astonishing phenomena exhibited by a galvanic circle. Experiments establishing this point are abundant and conclusive. In fact, Faraday has recently shown that in some cases, at least, excitation takes place decisively *before* contact.

Fig. 48.



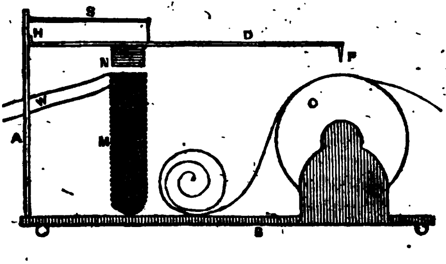
Thus, if a plate of zinc *cax*, figure 48, bent at right angles be placed opposite one of platinum *b*, soldered to a platinum wire *bsx*, the point of which *x* rests on a piece of bibulous paper moistened with a solution of iodide of potassium, care being taken to avoid contact of the metals, a current of electricity notwithstanding, at once flows in the direction of the arrows, when the plates are introduced in a dilute acid, as will be shown by the decomposition of the iodide of potassium, and by the galvanometer. So also the spark passes between the wires attached to the two plates of the single circle *before* they are brought in contact.

281. The theory of Wollaston receives strong confirmation from the discovery of Faraday of the definite nature of electro-chemical action. He has shown that in a galvanic circle in which no excess of zinc is oxydized, the quantity of this metal dissolved in a given time from each plate is in a constant ratio both to the hydrogen liberated at the corresponding copper plate, and also at the negative electrode. For every grain of hydrogen evolved, 32.3 grs. of zinc are dissolved; and, on the other hand, the quantity of electricity evolved by the oxydation of 32.3 grains of zinc is just sufficient to decompose 9 grains of water, which, as we shall hereafter see, contain precisely 1 grain of hydrogen. Indeed, he has proved that electro-chemical decomposition is perfectly definite; the same absolute quantity of electricity always evolving the ingredients of compound bodies in invariable proportions. Thus, the quantities of hydrogen, oxygen, tin, and lead, separated from their compounds by the same quantity of electricity, he found to be in the ratio of the numbers 1, 8, 57.9, and 103.6, which he therefore proposes to call the *electro-chemical equivalents* of these substances. They are identical, as we shall hereafter see, with the atomic weights of these substances.

282. *Electro-Chemical Theory.*—This theory, which was first started by Davy in 1807, supposes that electrical and chemical attractions are owing to one and the same agent. Substances in their uncombined state, it is

282. *The Magnetic Telegraph.*—The science of electro-magnetism has recently been applied to an important practical purpose, in the construction of *magnetic telegraphs*, for conveying information from place to place. The idea of such instruments was first suggested, it is believed, by Professor S. F. B. Morse, of New York; but they have also been constructed in Europe by Mr. Wheatstone and others.

Fig. 48*.



283. The magnetic telegraph of Professor Morse is constructed in the following manner. Figure 48* represents a side view of the instrument. AB is a firm frame of wood, and C a cylinder, which is made to turn with a uniform velocity by means of clockwork, not represented in the

figure. M is a horse-shoe magnet, or rather, it is a piece of soft iron bent in the form of a horse-shoe, and covered with copper iron, which is wound many times around it in the manner already explained (267); the two ends of the wire being seen at W. N is one end of the armature or keeper, which is attached by a screw to the lever D; and S is a small spring of steel, of just sufficient strength to sustain the weight of both the lever and armature. At H the lever is connected with the frame of the instrument by a hinge, and at P is a steel point which acts as a pencil to mark upon the paper as it is carried slowly along by the turning of the cylinder C.

The paper is used in the form of a long strip or ribbon, an inch and a half wide, made into a coil, and one end of it placed over the roller.

Let us suppose now that the two extremities of the iron, which is coiled around M, are connected with the poles of a galvanic battery, instantly the iron M becomes magnetic, and draws the armature N down to it, bringing the point P down upon the paper; and if the circuit is broken by lifting one of the wires from the pole of the battery, the lever and armature will be instantly raised again to their present position. If now the cylinder C is put in motion, slowly carrying the paper along with it, when the circuit is closed and instantly broken, the point P simply makes a dot upon the paper, but if the circuit remain closed for any length of time a line is formed. Now this takes place instantly, whatever may be the length of the wires, or in other words, whatever may be the distance of the battery from the telegraph; whether it be a few feet or rods, or many miles;—only for great distances a more powerful battery is required than for small distances.

284. It will be seen by the above, that the only characters the telegraph is capable of forming are dots and straight lines, but, by means of these, a perfect alphabet can easily be formed. Thus, for instance, as in Morse's alphabet, let a dot and a straight line (. —) be A; a straight line and three dots (— . . .) B; three dots (. . .) C; a straight line and two dots (— . .) D; a single dot (.) E; &c., and a very simple alphabet is formed, by which communications can be made with considerable rapidity.

Let us now suppose that a communication is to be made between two places at a distance from each other, as from Washington to Baltimore. The telegraph is in Baltimore, and the galvanic battery which puts it in action is in Washington; the two wires W being perfectly insulated, and extending quite from one to the other. The operator in Washington first gives a signal to the one in Baltimore, who immediately puts the clock-work of the telegraph in motion, by which the paper is carried slowly forwards. The operator in Washington, then, by closing and breaking the circuit at the battery, in the manner already described, causes the telegraph in Baltimore to write any combination of lines and dots he chooses; which will be perfectly intelligible to the operator there, and to any one who understands the alphabet. Thus a means of communication is established between the two places, by which intelligence may be transmitted almost with the rapidity of thought.

But as the earth is a good conductor of electricity, it is found that only one wire is absolutely needed to extend from one place to the other; instead of the other wire extending the whole distance, a short one only is necessary, to connect the battery with the moist earth beneath it, and another, in like manner, to reach from the telegraph to the moist earth.

In order that a reply may be returned from Baltimore to Washington, in the above supposed case, it is of course necessary that a telegraph should be located in the same manner in Washington, and connected with a battery in Baltimore.

The wires, as before intimated, must be perfectly insulated; which is accomplished by having them covered with cotton thread, and smeared with varnish or pitch; and either inclosed in lead tubes and buried in the ground, or extended in the air upon [illegible] of high posts.

PART II.

INORGANIC CHEMISTRY.

CHAPTER I.

CHEMICAL COMBINATIONS.

SECTION I.

PRELIMINARY REMARKS:—CHEMICAL NOMENCLATURE.

285. BEFORE proceeding to the discussion of the various elementary substances and their compounds, to which the second part of our work is to be devoted, it is necessary to attend to an explanation of the leading doctrines of the science. This will be done under the general head of CHEMICAL COMBINATIONS.

286. In addition to the chemical history of each substance, some of its chief physical characters will also be given. A knowledge of these properties is absolutely essential to the chemist for various important purposes.

287. The character called *specific gravity*, in particular, is of so much importance, that the mode of determining it will be given in this place.

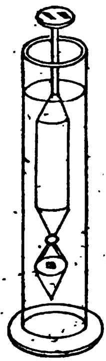
By the specific gravity of a body is meant its weight as compared with some other body assumed as a standard. For solids and liquids, water is uniformly taken for this standard; and its specific gravity being considered as unity, the specific gravity of any other body is found by dividing its weight by the weight of an equal volume of water. If, for example, a portion of water weigh 9 grains, and the same bulk or volume of another body 19 grains, dividing 19 by 9 gives as the quotient 2.111, which is the specific gravity of the body. The only difficulty there is in the practical application of the principle is, to obtain the weights of precisely equal volumes of water and the substance to be examined. In liquids this object is accomplished by filling a small vial of known weight with pure water, and weighing it, and then doing the same with the liquid in question. The weight of the latter divided by that of the former will, of course, be the specific gravity. Bottles are prepared for this purpose by the philosophical instrument-makers, capable of holding precisely 1000 grains of pure water; and of course the number of grains of any other liquid one of them will contain, pointing off three figures to the right for decimals, will be its specific gravity,

288. An instrument called a hydrometer has been invented for determining the specific gravity of liquids, in a very simple manner. It consists merely of a glass tube with a bulb blown in it for an air-vessel, and another at one extremity to contain a little mercury to load it and make it stand upright in the liquid. The weight of the instrument is therefore constant, and the specific gravity of a liquid in which it is immersed is shown by the depth to which it sinks, the weight of the quantity of fluid displaced, of course, always just equalling the weight of the instrument. The lighter the liquid is, therefore, the deeper will the hydrometer sink, and the reverse. In some liquids, as alcohol and the ethers, the strength is greater as they become lighter; but in others, as vegetable infusions or solutions of the fixed alkalies, and salts, the strength increases with the specific gravity.

289. The method of obtaining the necessary data in case of a solid is somewhat different. The body is first weighed in air, is next suspended in water by means of a hair attached to the scale of the balance, and is then weighed again. The difference between the two weights gives the weight of a quantity of water equal to the bulk of the solid. This rule is founded on the hydrostatic law, that a solid body, immersed in any liquid, not only weighs less than it does in air, but the difference corresponds exactly to the weight of liquid which it displaces; and it is obvious that the liquid so displaced is exactly of the same dimensions as the solid.

290. Nicholson's Areometer, or gravimeter, as it has been called by some, furnishes an expeditious means for determining the specific gravity of solids with considerable accuracy. It is particularly useful for determining the specific gravity of small substances, as specimens of minerals, in a simple manner. It is composed simply of a cylindrical air-vessel, terminating in a cone at each extremity, and loaded with a weight at one end to make it stand upright when immersed in water, and which at the same time serves as a table or scale, on which any small substance may be placed and weighed under water, while from the other extremity a wire projects to the height of an inch or more to receive another scale. To make use of this instrument, having placed it in water, as represented in figure 49, first place weights upon the upper scale and ascertain the weight hat is required to sink it to the mark upon the stem, then removing the weights, place upon the same scale the substance to be weighed—a piece of coin,—for instance,—and add as much weight as will sink it to the mark on the stem as before; the difference will of course be the weight of the coin. The coin is then to be transferred to the lower scale, and as much weight added as will again bring the mark on the stem to the surface

Fig. 40.



of the water. This weight is obviously the loss of weight of the coin in consequence of being immersed in water, or the weight of a bulk of water equal to the bulk of the coin. This divided into the weight of the coin will give its specific gravity.

There will be no difficulty in finding the specific gravity of bodies lighter than water, as a piece of cork, if it is remembered that the weight of a bulk of water equal to it, will be equal to the weight of the cork added to the weight required to cause it to sink in water.

The water used is always supposed to be perfectly pure, and at the temperature of 60°. In France, water at its greatest density is taken as the standard, that is, at the temperature of between 39 and 40°.

291. The determination of the specific gravity of gaseous substances is an operation of much greater delicacy. From the extreme lightness of gases, it would be inconvenient to compare them with an equal bulk of water, and, therefore, atmospheric air is taken as the standard of comparison. The first step of the process is to ascertain the weight of a given volume of air. This is done by weighing a very light glass flask, furnished with a good stopcock, while full of air; and then weighing it a second time, after the air has been withdrawn by means of an air-pump. The difference between the two weights gives the information required. According to the observations of Prout, 100 cubic inches of pure and dry atmospheric air, at the temperature of 60°, and when the barometer stands at 30 inches, weigh 31.01 grains. By a similar method the weight of any other gas may be determined, and its specific gravity be inferred accordingly. For instance, suppose 100 cubic inches of oxygen gas are found to weigh 34.19 grains, its specific gravity will be thus deduced; as 31.01 : 34.19 : : 1 (the sp. gr. of air) : 1.10, the specific gravity of oxygen.

292. In taking the specific gravity of gases, to insure any degree of accuracy, several circumstances require particular attention. The gas must not only be perfectly pure and dry, but the temperature and pressure must be invariable and at a proper standard. In general, the temperature is supposed to be at 60° and the barometer at 30 inches; and if, at the time of making the experiment, either is different, the proper correction is to be made.

In describing the gases, the weight of 100 cubic inches is usually mentioned in connection with the specific gravity.

293. *Chemical Nomenclature.*—Chemistry is indebted for its nomenclature to the labors of four celebrated chemists, Lavoisier, Berthollet, Guyton-Morveau, and Fourcroy. The principles which guided them in its construction are exceedingly simple and ingenious. The known elementary substances, and the more familiar compound ones, were allowed to retain the

appellation which general usage had assigned to them. The newly-discovered elements were named from some striking property. Thus oxygen, (a name applied to one of the elements of water) from οξυς, acid, and γενιαω, to generate, was so called from the belief that it is the universal cause of acidity; and the term hydrogen, from υδωρ, water, and γενναω, was applied to the other element of water. So also chlorine, in consequence of its greenish color, receives its name from χλωρος, green; while bromine is indebted for its name to its disagreeable odor.

294. Compounds, of which oxygen forms a part, are called *acids** or *oxides*, according as they do or do not possess acidity. An oxide of iron or copper signifies a combination of those metals with oxygen, which has no acid properties. The name of an acid is derived from the substance acidified by the oxygen, to which is added the termination *ic*. Thus, sulphur*ic* and carbon*ic* acids signify acid compounds of sulphur and carbon with oxygen. If sulphur or any other body should form two acids, that which contains the least quantity of oxygen is made to terminate in *ous*, as sulphur*ous* acid.

Here it will be noticed that provision is made in the nomenclature for only two acids formed from the same substance by the union of oxygen; but when three or more occur, the prefix *hypo* is generally used to indicate the relative proportion of oxygen. Thus *hypo*sulphurous acid contains less oxygen than the sulphurous, and hyposulphuric less than the sulphuric, but more than the sulphurous. The syllables *per* and *oxy* are also often used; thus *per* or *oxy*-chloric acid is an acid containing more oxygen than the chloric.

295. But it is well known there are other acids which contain no oxygen; these usually receive for names terms compounded of the names or parts of the names of the substances entering into their composition. Thus *hydro-chloric* acid is composed of hydrogen and chlorine, *chloriodic*, of chlorine and iodine, &c.

296. This system, however, does not apply to the acids of organic substances, which sometimes are derived from the names of the substances that yield them, and sometimes are suggested by mere accident. Further remarks on the subject will be found in Organic Chemistry.

297. The termination *uret* is used to denote combinations of the simple non-metallic substances either with one another, with a metal, or with a metallic oxide. Sulph*uret* and carb*uret* of iron, for example, signify compounds of sulphur and carbon with iron. The different oxides or sulphurets of the same

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* It is generally considered characteristic of an acid to change the vegetable blue to red, but there are many exceptions. An alkali will restore the original blue, or sometimes change it to green. The yellow color of turmeric is changed to brown by an alkali.

substance were formerly distinguished from one another by some epithet, commonly derived from the color of the compound, such as the black and red oxides of iron, the black and red sulphurets of mercury; though this practice is still continued occasionally, it is now more customary to distinguish degrees of oxydation by the use of derivatives from the Greek or Latin. *Prot*oxide signifies the first degree of oxydation, *bin*oxide the second, and *ter*oxide the third; and the term *per*oxide is often applied to the highest degree of oxydation. The Latin word *sesqui*, one and a half, is used as an affix when the elements of an oxide are as 1 to 1½, or as 2 to 3. The sulphurets, carburets, &c. of the same substance are designated in a similar manner.

298. The term *uret* is, however, less used now than formerly, there being no reason why we should adopt this in a few cases only, and still make use of *ide* in analogous instances. Protosulphuret and bisulphuret of iron, therefore, are terms perfectly synonymous with protosulphide and bisulphide of iron.

299. The general term *salt* is applied to the compounds of the acids with ammonia, and the alkaline bases and other metallic oxides; and their names are so contrived as to indicate the substances contained in them. If the acid contain a maximum of oxygen, the name of the salt terminates in *ate;* if a minimum, the termination *ite* is employed. Thus, the sulph*ate*, phosph*ate*, and arseni*ate* of potassa, are salts of sulphur*ic*, phosphor*ic*, and arsen*ic*, acids: while the terms sulph*ite*, phosph*ite*, and arsen*ite* of potassa, denote combinations of that alkali with the sulphur*ous*, phosphor*ous*, and arseni*ous* acids.

300. But each of these acids may unite with the protoxide, binoxide, or peroxide of the same substance, and to distinguish the salts thus formed it is usual to prefix the numeral to the name of the salt in the same manner as to the oxide. Thus we have protosulphate and persulphate of mercury to designate the sulphates of the protoxide and per or binoxide of mercury. We cannot, however, say bisulphate of mercury, to designate the sulphate of the binoxide, as this term has another application, as will shortly appear; and it is therefore thought better by many, to avoid mistake, always to say sulphate of the proto, bi, or peroxide.

301. The different salts formed of the same constituents were formerly divided into *neutral*, *super*, and *sub*-salts. They were called neutral if the acid and alkali were in such proportion that one neutralized the other; super-salts, if the acid prevailed, and sub-salts, if alkali was in excess. The name is now regulated by the atomic constitution of the salt. To a salt formed of a single equivalent of acid and alkali, the generic name of the salt is employed without any other addition; but if two or more equivalents of the acid are attached to one of the base, or two or more equivalents of the base to one of the acid, a numeral is prefixed so as to indicate its composition.

The two salts of sulphuric acid and potassa are called sulphate and *bi*sulphate; the first containing one equivalent of the acid and one of the alkali, and the second salt, two equivalents of the former substance to one equivalent only of the latter. The three salts of oxalic acid and potassa are termed the oxalate, *bin*oxalate, and *quad*roxalate of potassa: because one equivalent of the alkali is united with one equivalent of acid in the first, with two in the second, and with four in the third salt.

302. The numerals which denote the equivalents of acid in a super-salt are derived from the Latin, as *bi*, *ter*, *quadro*, while those used to indicate the same with regard to the equivalents of base in a sub-salt, are derived from the Greek, as *dis*, *tris*, *tetrakis*. Thus bichromate of potassa contains 2 equivalents of acid and 1 eq. of potassa; but the dichromate of oxide of lead contains 1 eq. of acid and 2 eq. of oxide of lead. This principle has been considerably extended; and it is now common to distinguish two or more equivalents of the negative element by Latin numerals, and apply the Greek numerals to designate the equivalents of the positive element. Thus a bichloride is a compound of 2 equivalents of the electro-negative element chlorine, with 1 eq. of some electro-positive substance; but a dichloride contains 1 eq. of chlorine in combination with 2 eq. of the positive element.

The super-salts having an excess of acid are also called acid salts; and for a similar reason the sub are often called basic salts. Monobasic, bibasic, and tribasic salts are such as contain 1, 2, and 3 eq. of base to 1 eq. of acid.

303. The generic part of the name of a compound is also usually formed from that ingredient which is most highly electro-negative. Thus, to compounds of oxygen and chlorine, chlorine and iodine, iodine and sulphur, sulphur and potassium, in which the first of each pair is the electro-negative element, we say oxides of chlorine, chloride of iodine, iodide of sulphur, sulphuret of potassium; and not chloride of oxygen, iodide of chlorine, &c.

The term salt has within a few years received a much more extended signification than is given above (299); but the further discussion of the subject is reserved for the Chapter upon Salts.

SECTION II.

AFFINITY.

304. All chemical phenomena are owing to Affinity or Chemical Attraction. It is the basis on which the science of chemistry is founded. It is, as it were, the instrument which

the chemist employs in all his operations, and hence it forms the first and leading object of his study.

305. Affinity is exerted between the minutest particles of different kinds of matter, causing them to combine so as to form new bodies endowed with new properties. It acts only at insensible distances; in other words, apparent contact, or the closest proximity, is necessary to its action. Every thing which prevents such contiguity is an obstacle to combination; and any force which increases the distance between particles already combined, tends to separate them permanently from each other. In the former case, they do not come within the sphere of their mutual attraction; in the latter, they are removed out of it. It follows, therefore, that, though affinity is regarded as a specific power, distinct from the other forces which act on matter, its action may be promoted, modified, or counteracted by them; and, consequently, in studying the phenomena produced by affinity, it is necessary to inquire into the conditions that influence its operation.

306. The most simple instance of the exercise of chemical attraction is afforded by the admixture of two substances. Water and sulphuric acid, or water and alcohol, combine readily. On the contrary, water shows little disposition to unite with sulphuric ether, and still less with oil; for, however intimately their particles may be mixed together, they are no sooner left at rest than the ether separates almost entirely from the water, and a total separation takes place between that fluid and the oil. Sugar dissolves very sparingly in alcohol, but to any extent in water; while camphor is dissolved in a very small degree by water, and abundantly by alcohol. It appears, from these examples, that chemical attraction is exerted between different bodies with different degrees of force. There is sometimes no proof of its existence at all; between some substances it acts very feebly, and between others with great energy.

307. *Single Elective Affinity.*—Simple combination of two substances is a common occurrence; of which the solution of salts in water, the combustion of phosphorus in oxygen gas, and the neutralization of a pure alkali by an acid, are instances. But the phenomena are often more complex. The formation of a new compound is often attended by the destruction of a pre-existing one; as when some third body acts on a compound, for one element of which it has a greater affinity than they have for one another. Thus, oil has an affinity for the volatile alkali, ammonia, and will unite with it, forming a soapy substance called a liniment. But the ammonia has a still greater attraction for sulphuric acid, and hence, if this acid be added to the liniment, the alkali will quit the oil, and unite by preference with the acid. If a solution of camphor in alcohol be poured into water, the camphor will be set free, because the alcohol combines with the water. Sulphuric acid, in like man-

ner, separates baryta from nitric acid. Combination and decomposition occur in each of these cases;—combination of sulphuric acid with ammonia, of water with alcohol, and of baryta with sulphuric acid;—decomposition of the compounds formed of oil and ammonia, of alcohol and camphor, and of nitric acid and baryta. These are examples of *single elective affinity;* so called because a substance manifests, as it were, a choice for one of two others, uniting with it by preference, and to the exclusion of the other. Many of the decompositions that occur in chemistry are instances of single elective affinity.

308. It was at one time supposed that these decompositions always take place in the same order, independently of circumstances; and tables of decomposition were drawn up, of which the following are examples:—

Soda.	*Sulphuric-Acid.*
Sulphuric acid,	Baryta,
Nitric acid,	Strontia,
Hydrochloric acid,	Potassa,
Acetic acid,	Soda,
Carbonic acid,	Lime,
	Ammonia,
	Magnesia.

The first table was designed to indicate the relative strength of the affinity of soda for the several acids placed below it; thus the affinity of soda for sulphuric acid is greater than for nitric or any of the other acids below it, while the affinity of soda for nitric acid is greater than for the hydrochloric, &c. As a necessary consequence of this, each of the acids mentioned, it was supposed, would separate soda from its combination with either of the acids below it, and be itself separated from this solution by those above it.

By the second table the relative affinities of sulphuric acid for the several bases mentioned below it were indicated, and the order in which its compounds with these bases would be decomposed.

Nor were these tables founded upon hypothesis alone; they exhibited the results of numerous most accurate experiments, and their truth was supposed to be demonstrated.

309. Such tables, however, cannot be relied upon, as the chemical action of two or more substances does not arise simply from their chemical affinities, but results from the combined influences of heat, electricity, cohesion, and other agencies, which often modify the results to a remarkable extent. By a change of temperature, an affinity originally weak, may become very strong, and even preponderate over others previously much stronger than itself; and in certain electrical conditions (230), powerful affinities may be entirely overcome. Chemical action, therefore, is to be regarded, not as the simple consequence of affinity alone, but as the result of a number of forces acting in different directions, and with variable intensities, of which affinity is but one, although perhaps, for our purpose, it may be more important than any other.

310. We may indeed find in the variableness of intensity with which affinity is exerted, a striking instance of Creative Wisdom; for on it depends the infinite variety both of organic and inorganic beings, which people and beautify the earth. Had those bodies which have the strongest affinity for each other, in all cases been able to combine, independent of

other influences; then it would seem there could have been no means of dissolving their connection when once formed; and immediately on the origin of the globe, those bodies which have the strongest affinities would have united never again to be separated; and the others subsequently combining in the order of their attractions, the various substances of nature would long since have been arranged in a few unchangeable chemical combinations. The diversified changes of animal and vegetable life would be impossible, and the surface of the earth must for ever remain desolate and barren.

311. *Double Elective Affinity.*—Affinity is the cause of still more complicated changes than those which have been just considered. In a case of single elective affinity, three substances only are present, and two affinities are in play. But it frequently happens that two compounds are mixed together, and four different affinities brought into action. The changes that may or do occur under these circumstances may be studied by aid of a diagram. Thus, in mixing together a solution of carbonate of ammonia and hydrochlorate of lime, their mutual action may be represented in the following manner:

Carbonic acid   Ammonia

Hydrochloric acid   Lime.

Each of the acids has an attraction for both bases, and hence it is possible either that the two salts should continue as they were, or that an interchange of principles should ensue, giving rise to two new compounds—carbonate of lime and hydrochlorate of ammonia.

312. The affinities which tend to preserve the original compounds have been called the *quiescent*, and those which tend to cause an exchange of principles, the *divellent* affinities. If the sum of the former is greatest, that is, in the present instance, if the affinity of carbonic acid for ammonia, and hydrochloric acid for lime, exceed that of carbonic acid for lime, added to that of hydrochloric acid for ammonia, then will the two salts experience no change whatever; but if the divellent affinities preponderate, then, as does actually happen, both the original salts will be decomposed and two new ones generated. Two decompositions and two combinations take place, being an instance of what is called *double elective affinity.*

But the effect cannot always here, more than in cases of single elective affinity, be ascribed to the sole influence of affinity; circumstances often change entirely the character of the results.

CIRCUMSTANCES THAT MODIFY AND INFLUENCE THE OPERATION OF AFFINITY.

313. Of the conditions which are capable of promoting or counteracting the tendency of chemical attraction, the following are the most important;—cohesion, elasticity, quantity of matter, and contact with other bodies. To these may be added the agency of heat, electricity, and light. The influence of the last two agents has already been discussed in the proper places (154, 157, 230); that of heat will be considered under the heads of cohesion and elasticity.

314. *Cohesion.*—The first obvious effect of cohesion is to oppose affinity, by impeding or preventing that mutual penetration and close proximity of the particles of different bodies, which are essential to the successful exercise of their attraction. For this reason, bodies seldom act chemically in their solid state; their molecules do not come within the sphere of attraction, and, therefore, combination cannot take place, although their affinity may in fact be considerable. Liquidity, on the contrary, favors chemical action; it permits the closest possible approximation, while the cohesive power is comparatively so trifling as to oppose no appreciable barrier to affinity.

In a few instances chemical action takes place between solids, as between phosphorus and sulphur or phosphorus and iodine.

Cohesion may be diminished in two ways, by mechanical division, or by the application of heat. The former is useful by increasing the extent of surface; but it is not of itself in general sufficient, because the particles, however minute, still retain that degree of cohesion which constitutes solidity. Heat acts with greater effect, and never fails in promoting combination, whenever the cohesive power is a barrier to it. Its intensity should always be so regulated as to produce liquefaction. The fluidity of one of the substances frequently suffices for effecting chemical union, as is proved by the facility with which water dissolves many salts and other solid bodies. But the cohesive force is still in operation; for a solid is commonly dissolved in greater quantity when its cohesion is diminished by heat.

315. Cohesion sometimes even determines the results of chemical action, probably in opposition to affinity. Thus, on mixing together a solution of two acids and one alkali, of which two salts may be formed, one soluble, and the other insoluble, the alkali will always unite with that acid, with which it forms the insoluble compound, to the total exclusion of the other. When, for example, hydrochloric acid, sulphuric acid, and baryta, are mixed together, sulphate of baryta is formed in consequence of its insolubility. Lime, which yields an insoluble

salt with carbonic acid, separates that acid from ammonia, potassa, and soda, with all of which it makes soluble compounds.

Acetic acid doubtless has a stronger affinity for potassa than carbonic acid has, for when poured into a solution of carbonate of potassa in water, the carbonic acid is expelled with effervescence; but if a stream of carbonic acid is passed into a solution of acetate of potassa in alcohol, the salt is decomposed, the acetic acid set free, and carbonate of potassa formed. The cause of this is the insolubility of carbonate of potassa in alcohol.

316. *Elasticity.*—From the obstacle which cohesion puts in the way of affinity, the gaseous state, in which the cohesive power is wholly wanting, might be expected to be peculiarly favorable to chemical action. The reverse, however, is the fact. Bodies evince little disposition to unite when presented to each other in the elastic form. Combination does, indeed, sometimes take place, in consequence of a very energetic attraction; but examples of an opposite kind are much more common. Oxygen and hydrogen gases, and chlorine and hydrogen, though their mutual affinity is very powerful, may be preserved together for any length of time without combining. This want of action seems to arise from the distance between the particles, preventing that close approach which is so necessary to the successful exercise of affinity. Hence many gases cannot be made to unite directly, which, nevertheless, combine readily while in their *nascent* state; that is, while in the act of assuming the gaseous form by the decomposition of some of their solid or fluid combinations.

317. Many familiar phenomena of decomposition are owing to elasticity. All compounds that contain a volatile and a fixed principle, are liable to be decomposed by a high temperature. The expansion occasioned by heat removes the elements of the compound to a greater distance from each other, and thus, by diminishing the force of chemical attraction, favors the tendency of the volatile principle to assume the form which is natural to it. The evaporation of water from a solution of salt is an instance of this kind.

Many solid substances, which contain water in a state of intimate combination, part with it in a strong heat, in consequence of the volatile nature of that liquid. The separation of oxygen from some metals, by heat alone, is explicable on the same principle.

318. The influence of heat upon chemical action is therefore variable, sometimes tending to promote it, and at others preventing it altogether. Whenever cohesion interposes an obstacle to the action of affinity, heat facilitates it by diminishing the cohesive attraction, if a solid, or even converting it into a liquid. On the contrary, when a substance is converted by it into a gas, chemical combination is prevented in consequence of the great distance to which the particles are separated from each other.

319. Some instances of decomposition may even be ascribed to elasticity. If three substances are mixed together, two of which are capable of forming a compound which is less volatile than the third body, the last will, in general, be completely driven off by the application of heat. The decomposition of the salts of ammonia by the pure alkalies or alkaline earths, may be adduced as an example; and for the same reason, all the carbonates are decomposed by hydrochloric acid, and all the hydrochlorates by sulphuric acid. This explanation applies equally well to some cases of double decomposition. It explains, for instance, why the dry carbonate of lime will decompose hydrochlorate of ammonia by the aid of heat; for carbonate of ammonia is more volatile than the hydrochlorate either of ammonia or lime.

So if sulphate of ammonia and hydrochlorate of soda are mixed, and heat applied, hydrochlorate of ammonia sublimes, and sulphate of soda remains fixed. Boracic acid may readily be entirely separated from its combination with soda by sulphuric acid; but if this acid is heated to redness with sulphate of soda, the sulphuric acid will be expelled in consequence of its volatility at high temperatures, and the boracic acid will remain in combination with the soda.

320. *Quantity of Matter.*—The influence of quantity of matter over affinity is universally admitted. If one body A unites with another body B in several proportions, that compound will be most difficult of decomposition which contains the smallest quantity of B. Of the three oxides of lead, for instance, the peroxide parts most easily with its oxygen by the action of heat; a higher temperature is required to decompose the red oxide; and the protoxide will bear the strongest heat of our furnaces without losing a particle of its oxygen.

The influence of quantity over chemical attraction may be farther illustrated by the phenomena of solution. When equal weights of a soluble salt are added in succession to a given quantity of water, which is capable of dissolving almost the whole of the salt employed, the first portion of the salt will disappear more readily than the second, the second than the third, the third than the fourth, and so on. The affinity of the water for the saline substance diminishes with each addition, till at last it is weakened to such a degree as to be unable to overcome the cohesion of the salt. The process then ceases, and a saturated solution is obtained.

Quantity of matter is employed advantageously in many chemical operations. If, for instance, a chemist is desirous of separating an acid from a metallic oxide by means of the superior affinity of potassa for the former, he frequently uses rather more of the alkali than is sufficient for neutralizing the acid. He takes the precaution of employing an excess of alkali, in order the more effectually to bring every particle of the substance to be decomposed in contact with the decomposing agent.

321. *Contact with other bodies.*—The simple contact of other bodies in some instances essentially affects the action of affinity. Thus, if a coil of platinum wire be heated to redness and suspended in a glass vessel, the inside of which has previously been moistened with strong alcohol or ether, a slow combustion of the vapor immediately takes place, and the tempera-

ture of the wire is kept up. So also a mixture of oxygen and hydrogen gases is made to explode by a small ball of spongy platinum, or in some cases by very clean platinum foil, though of themselves, when brought together, they show no tendency to combine. The platinum has the effect to condense a portion of these gases upon its surface, by which heat is produced; and a union takes place at first slowly between small portions only of the mixture, but as soon as the temperature is sufficiently raised, extends instantaneously through the whole that remains, with an explosion. When platinum sponge is used the action is much facilitated by the great amount of surface which acts upon the gases within a very limited space.

322. Instances of chemical action, like the above, cannot of course be attributed to the action of mere affinity, and it has been supposed another force must come into operation called a *catalytic force*; and the term *catalysis* has been used to designate the class of operations.

The sudden decomposition of explosive bodies by a blow, or by elevation of temperature, are also instances of catalysis. Platinum, which by itself is totally unacted upon by nitric acid, is readily dissolved by a connection with silver in the form of alloy; and copper, though unaffected by sulphuric acid when pure, is easily soluble by it when alloyed with zinc and nickel, in the compound called German silver. But the most important instances of catalysis are to be found in the chemistry of organic matter, which it would be premature here to anticipate.

323. *Mechanical action* also may be mentioned as frequently modifying the action of affinity. Thus its commencement, as in the case of fulminating mercury or a mixture of chlorate of potassa and sugar, is determined by a blow; and two elastic fluids may sometimes be made to combine by sudden compression. Water under high pressure will combine with much more carbonic acid than when the pressure is less. Carbonate of lime is decomposed at a high temperature in the open air, but under strong pressure it may be melted without producing this effect.

CHANGES THAT ACCOMPANY CHEMICAL ACTION.

324. The leading circumstance that characterizes chemical action is the loss of properties experienced by the combining substances, and the acquisition of new ones by the product of their combination. The change of property is sometimes inconsiderable. In a solution of sugar or salt in water, and in mixtures of water with alcohol or sulphuric acid, the compound retains so much of the character of its constituents that there is no difficulty in recognizing their presence. But more generally the properties of one or both of the combining bodies disappear entirely. One would not suppose from its appearance that water is a compound body; much less that it is composed of two gases, oxygen and hydrogen, neither of which when uncombined, has ever been compressed into a liquid. Hydrogen is one of the most inflammable substances in nature, and yet water cannot be set on fire; oxygen, on the contrary, enables bodies to burn with great brilliancy, and yet water extinguishes combustion. The alkalies and earths were regarded as simple till Davy proved them to be compound, and certainly they evince no sign whatever of containing oxygen

and metal. Numerous examples of a similar kind are afforded by the mutual action of acids and alkalies. Sulphuric acid and potassa, for example, are highly caustic. The former is intensely sour, reddens the blue color of vegetables, and has a strong affinity for alkaline substances; the latter has a pungent taste, converts the blue color of vegetables to green, and combines readily with acids. On adding these principles cautiously to each other, a compound results called a *neutral salt*, which does not in any way affect the coloring matter of plants, and in which the other distinguishing features of the acid and alkali can no longer be perceived. They appear to have destroyed the properties of each other, and are hence said to *neutralize* one another.

325. The changes that accompany the action of affinity are many and important; nor is it possible to determine any of the properties a compound will possess merely by knowing the nature of the ingredients that enter into its composition.

1. It is observed that two bodies rarely occupy, after combination, the same space which they possessed separately. In general their bulk is diminished, so that the specific gravity of the new body is greater than the mean of its components. Thus a mixture of 100 measures of water and an equal quantity of sulphuric acid does not occupy the space of 200 measures, but considerably less. A similar contraction frequently attends the combination of solids. Gases often experience a remarkable condensation when they unite. The elements of olefiant gas, for instance, would expand to four times the bulk of that compound, if they were suddenly to become free, and assume the gaseous form. But the rule is not without exception. The reverse happens in some metallic compounds; and there are examples of combination between gases without any change of bulk.

2. A change of temperature generally accompanies chemical action. Heat is evolved, either when there is a diminution in the bulk of the combining substances without change of form, or when a gas is condensed into a liquid, or a liquid becomes solid. The heat caused by mixing sulphuric acid with water is an instance of the former; and the common process of slaking lime, during which water loses its liquid form in combining with that earth, is an example of the latter. The production of cold seldom or never takes place during combination, except when heat is rendered insensible by the conversion of a solid into a liquid, or a liquid into a gas. All the frigorific mixtures act in this way.

3. The changes of form that attend chemical action are exceedingly various. The combination of gases may give rise to a liquid, as in the union of olefiant gas and chlorine to form chloric ether, or of oxygen and hydrogen to form water; or to a solid, as in the union of carbonic acid gas and ammonia to

form solid carbonate of ammonia, or hydrochloric acid and ammonia, to form hydrochlorate of ammonia.

Two solids may in combining form a liquid, as is the case when crystals of sulphate of soda and nitrate of ammonia are rubbed together in a mortar, or acetate of lead and alum. Solids may also, in combining, form gases, as is the case when gunpowder detonates. Two liquids by uniting may form a solid, as may be shown by pouring sulphuric acid into a solution of hydrochlorate of lime.

4. Chemical action is frequently attended by change of color. No uniform relation has been traced between the color of a compound and that of its elements. Iodine, whose vapor is of a violet hue, forms a beautiful red compound with mercury, and a yellow one with lead. The black oxide of copper generally gives rise to green and blue-colored salts; while the salts of the oxide of lead, which is itself yellow, are for the most part colorless.

A beautiful instance of the change of color produced by chemical action is seen in mixing solutions of bichloride of mercury and iodide of potassium. The solutions may be made as perfectly limpid as water, but, upon being mixed, a beautiful vermilion red is produced by the formation of biniodide of mercury. The color shortly disappears, if either solution was in excess, by the re-dissolving of the precipitate.

The color of precipitates is a very important study, as it supplies a character by which most substances may be distinguished.

SECTION III.

LAWS OF COMBINATION—CHEMICAL PROPORTIONS.

326. The study of the proportions in which bodies unite naturally, resolves itself into two parts. The first includes compounds whose elements appear to unite in a great many proportions; the second comprehends those, the elements of which combine in a few proportions only.

The compounds contained in the first division are of two kinds. In one, combination takes place unlimitedly in all proportions; in the other, it occurs in every proportion within a certain limit. The union of water with alcohol and the liquid acids, such as the sulphuric, hydrochloric, and nitric, affords instances of the first mode of combination; the solutions of salts in water are examples of the second. One drop of sulphuric acid may be diffused through a gallon of water, or a drop of water through a gallon of the acid; or they may be mixed together in any intermediate proportions; and nevertheless, in each case they appear to unite perfectly with each other. A hundred grains of water, on the contrary, will dissolve any quantity of salt which does not exceed forty grains. Its solvent power then ceases, because the cohesion of the solid becomes comparatively too powerful for the force of affinity. The limit to combination is in such instances owing to the cohesive power; and, but for the obstacle which it occasions, the salt would most probably unite with water in every proportion.

327. All the substances which unite in many proportions give rise to compounds which have this common character, that their elements are united by a feeble affinity, and preserve, when combined, more or less of the properties which they possess in a separate state.

It should be remarked, however, that, though some substances, as above stated, appear to unite in every proportion, it may be so in appearance only; and there are indications which have induced the belief that chemical union between two or more substances takes place always in definite proportions. Thus, though some acids appear to unite with water in every proportion, yet there are certain relative quantities of acid and water which possess peculiar properties, and form the most energetic compounds. Mixtures of alcohol and water of different strength may contain the same definite compounds of these fluids mixed with each other in different proportions.

Many of the metals appear to combine with each other in indefinite proportions, but there are reasons for supposing that in these cases a few definite compounds are formed, which are variously mixed with each other. Thus Rudberg found that variable mixtures of metals in cooling after fusion, have generally two periods when the thermometer is stationary. In alloys of lead and tin, one of these points is uniformly at 368½° for all mixtures, while the other point varies according as one or the other metal is predominant, and is near the fusing point of the predominating metal. From this it is inferred that the latter point is caused by the congelation of the predominating metal, and the constant point is the congealing temperature of an alloy of uniform composition present in all the mixtures. This alloy is composed of three equivalents of tin and one equivalent of lead, its congealing point being 368½°. In variable mixtures of bismuth and tin, the constant point is 289½°, which is the congealing temperature of an alloy composed of single equivalents of tin and bismuth.

328. The most interesting series of compounds is produced by substances which unite in a few proportions only, and which, in combining, lose more or less completely the properties that distinguish them when separate. Of these bodies, some form but a single compound, while others unite in two and some in three, four, five, or more proportions.

The combination of substances that unite in a few proportions only is regulated by the following remarkable laws:—

1. *The composition and properties of bodies are fixed and invariable.*

A compound substance, so long as it retains its characteristic properties, always consists of the same elements united in the same proportion. Sulphuric acid, for instance, is always composed of sulphur and oxygen, in the ratio of 16.1 parts* of the former to 24 of the latter: no other elements can form it, nor can it be produced by its own elements in any other proportion. Water, in like manner, is formed of 1 part of hydrogen and 8 of oxygen; and were these two elements to unite in any other proportion, some new compound, different from water, would be the product. The same observation applies to all other substances, however complicated, and at whatever period they were produced. This law, in fact, is universal and permanent. Its importance is equally manifest: it is the essential basis of chemistry, without which the science itself could have no existence.

2. *If the numbers be determined which express the quantities of various substances, as B, C, D, &c., required to combine singly with a given quantity of another substance A, then these same numbers, or multiples of them, will also express the proportions in which any two will combine with each other, as B + C, C + D, B + D, &c.*

Thus, 16.1 parts of sulphur, 35.42 of chlorine, 39.6 of selenium, 108 of silver, and 1 of hydrogen, are severally capable of combining with 8 parts of oxygen; and it is found that when they combine with one another, they always unite either in the proportions expressed by those numbers, or multiples of them.

Numerous other similar instances might be given, as the law is universal.

329. It will readily be observed that the numbers used merely express the relative quantities of the substances they represent, that combine together; it is therefore in itself immaterial what figures are employed to express them. The only essential point is, that the relation should be strictly observed. Thus, the equivalent of hydrogen may be assumed as 10; but then oxygen must be 80, carbon 61.2, and sulphur 161. Thomson makes oxygen 1, so that hydrogen is eight times less than unity, or 0.125, carbon 0.76, and sulphur 2. Wollaston estimated oxygen at 10; and hence hydrogen is 1.25, carbon 7.6, and so on. According to Berzelius, oxygen is 100. And lastly, several other chemists, as Dalton, Davy, Henry, Turner, and others, selected hydrogen as their unit; and, therefore, the equivalent of oxygen is 8. One of these series may easily be reduced to either of the others by an obvious and simple cal-

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* Parts by weight are always intended unless it is otherwise expressed

culation. The numbers adopted in this work refer to hydrogen as unity.

There seems to be particular propriety in making the equivalent of hydrogen unity, since it is much smaller than the equivalent of any other known substance.

330. Having agreed upon the basis of our system of numbers for this purpose, it will be perceived that the number which represents the lowest combining proportion of any substance must always be the same, whatever may be the other substance with which it is made to unite. This number is expressed by the terms *combining proportional*, or *equivalent.* Thus the equivalent of hydrogen being 1, that of oxygen will be 8, sulphur 16.1, carbon 6.12, chlorine 35.42, silver 108., &c.

At page 136 will be found a table of the equivalents of the elementary substances.

This law does not apply to elementary substances only, since compound bodies have their combining proportionals or equivalents, which may likewise be expressed in numbers. Thus, since water is composed of one equivalent or 8 parts of oxygen, and 1 equivalent or 1 of hydrogen, its combining proportion or equivalent is 9. The equivalent of sulphuric acid is 40.1, because it is a compound of one equivalent or 16.1 parts of sulphur, and three equivalents or 24 parts of oxygen; and in like manner, the combining proportion of hydrochloric acid is 36.42, because it is a compound of one equivalent or 35.42 parts of chlorine, and one equivalent or 1 part of hydrogen. The equivalent number of potassium is 39.15, and as that quantity combines with 8 of oxygen to form potassa, the equivalent of the latter is $39.15+8=47.15$. Now when these compounds unite, one equivalent of the one combines with one, two, three, or more equivalents of the other, precisely as the simple substances do. The hydrate of potassa, for example, is constituted of 47.15 parts of potassa and 9 of water, and its equivalent is consequently $47.15+9=56.15$. The sulphate of potassa is composed of 40.1 sulphuric acid $+47.15$ potassa; and the nitrate of the same alkali of 54.15 nitric acid $+47.15$ of potassa. The equivalent of the former salt is, therefore, 87.25, and of the latter 101.3.

The composition of the salts affords a very instructive illustration of this subject; and to exemplify it still farther, a list of the equivalents of a few acids and alkaline bases is annexed:—

Hydrofluoric acid	19.68	Lime	28.5
Phosphoric acid	71.41	Soda	31.3
Hydrochloric acid	36.42	Potassa	47.15
Sulphuric acid	40.1	Strontia	51.8
Nitric acid	54.15	Baryta	76.7

331. It will be seen at a glance that the neutralizing power of the different alkalies is very different; for the equivalent of each base expresses

the quantity required to neutralize an equivalent of each of the acids. Thus 31.3 of soda, and 76.7 of baryta, combine with 54.15 of nitric acid, forming the neutral nitrates of soda and baryta. The same fact is obvious with respect to the acids; for 71.4 of phosphoric, 40.1 of sulphuric, unite with 76.7 of baryta, forming a neutral phosphate, and sulphate, of baryta.

From this law it follows (as stated by Olmsted, *Sil. Jour. xii.* 1,) that the respective quantities of any alkaline, earthy or metallic base, required to saturate a given quantity of any acid, are always in the same ratio to each other, to what acid soever they may be applied; and, as the converse of this, that the respective quantities of any acids, required to saturate a given quantity of any base, are always in the same ratio to each other, to what base soever they may be applied. It is hence evident, as was early noticed by chemists, and considered a curious fact, that when two neutral salts mutually decompose each other, the resulting salts must also necessarily be neutral.

3. *If a substance, A, is capable of combining in several different proportions with another substance, B, the several quantities of B, which, in the different compounds, unite with the same quantity of A, bear to each other very simple ratios, that usually may be represented by the numbers 1, 2, 3, 4, 5, &c., or 1, 1½, 2, 2½, 3, 3½, &c.*

332. In the first case it will be observed the second, third, &c. quantities, are multiples of the first, but in the second, of one-half of the first, for the numbers 1, 1½, 2, 2½, &c., are of course in the same ratio as the numbers 2, 3, 4, 5, 6, &c.

The compounds of nitrogen and oxygen furnish examples of combination in which the several quantities of oxygen are to each other in the ratio indicated by the first series of numbers above given. Thus,

Nitrous oxide contains	Nitrogen	14.15	Oxygen	8	1
Nitric oxide	do.	14.15	do.	16	2
Hyponitrous acid	do.	14.15	do.	24	3
Nitrous acid	do.	14.15	do.	32	4
Nitric acid	do.	14.15	do.	40	5

In the compounds of manganese and oxygen, the several quantities of oxygen united with the same quantity of manganese, are in the ratio of the second series of numbers. Thus,

Protox. of Manganese contains	Manganese	27.7	Oxygen	8	1
Sesquioxide	do.	27.7	do.	12	1½
Peroxide	do.	27.7	do.	16	2
Manganic acid	do.	27.7	do.	24	3
Permanganic acid	do.	27.7	do.	28	3½

In this series of compounds, one place, it will be observed, is wanting between the peroxide and manganic acid; and it may hereafter be filled by further research. In all these cases combination takes place between 1 equivalent of the first substance and 1, 2, 3, 4, &c., eq. of the second, or 2 of the first, to 3, 5, 7, &c., of the second. Still more complex arrangements may, of course, be conceived, such as 3 equivalents of one substance, to 4, 5, &c., of another; but though theoretically possible, the existence of such compounds has not been decidedly established.

This law of multiple proportions applies also to compound bodies of every class. Thus, the three compounds of chromic acid and potassa are composed as follows:—

Chromate of Potassa contains	Potassa	47.15	Chromic Acid	52.	1
Bichromate do.	do.	47.15	do.	104.	2
Terchromate do.	do.	47.15	do.	156.	3

4. *The gases unite by volume in very simple ratios, usually as 1 to 1, 1 to 2, or 1 to 3, 2 to 3, &c.* When condensation accompanies chemical action, as is often the case with the gases, the diminution of bulk is also in a simple ratio.

Sufficient illustration of this law will be found in the following table. In the first three examples no condensation takes place, as does in the others.

Volumes of Elements.		*Resulting Compounds.*
100 Chlorine.........+100 Hydrogen	yield	200 Hydrochloric acid.
100 Cyanogen........+100 Hydrogen	"	200 Hydrocyanic acid.
100 Oxygen ....+100 Nitrogen	"	200 Binoxide of Nitrogen.
100 Nitrogen ....+300 Hydrogen	"	200 Ammonia.
50 Oxygen ....+100 Hydrogen	"	100 Water.
100 Vapor of Sulphur.+600 Hydrogen	"	600 Hydrosulphuric acid.

333. The utility of being acquainted with the preceding important laws is almost too manifest to require mention. Through their aid, and by remembering the equivalents of a few elementary substances, the composition of an extensive range of compound bodies may be calculated with facility. Thus, by knowing that 6.12 is the equivalent of carbon, and 8 of oxygen, it is easy to recollect the composition of carbonic oxide and carbonic acid; the first consisting of 6.12 parts of carbon + 8 of oxygen, and the second of 6.12 carbon + 16 of oxygen. The equivalent of potassium is 39.15; and potassa, its protoxide, is composed of 39.15 of potassium + 8 of oxygen. From these few data, we know at once the composition of carbonate and bicarbonate of potassa; the former being composed of 22.12 parts of carbonic acid + 47.15 potassa, and the latter of 44.24 carbonic acid + 47.15 potassa.

From the same data, calculations, which would otherwise be difficult or tedious, may be made rapidly and with ease, without reference to books, and frequently by a simple mental process. The exact quantities of substances required to produce a given effect may be determined with certainty, thus affording information which is often necessary to the success of chemical processes, and of great consequence, both in the practice of the chemical arts, and in the operations of pharmacy.

334. The same knowledge affords a good test to the analyst by which he may judge of the accuracy of his results, and even sometimes correct an analysis which he has not the means of performing with rigid precision. Thus a powerful argument for the accuracy of an analysis is derived from the correspondence of its result with the laws of chemical union. On the contrary, if it form an exception to them, we are authorized to regard it as

doubtful; and may hence be led to detect an error, the existence of which might not otherwise have been suspected. If an oxydized body be found to contain one equivalent of the combustible with 7.99 of oxygen, it is fair to infer that 8, or one equivalent of oxygen, would have been the result, had the analysis been perfect.

335. The useful instrument, known by the name of the *Scale of Chemical Equivalents*, was originally devised by Wollaston, and is a table of equivalents, comprehending all those substances which are most frequently employed by chemists in the laboratory; and it only differs from other tabular arrangements of the same kind, in the numbers being attached to a sliding rule, which is divided according to the principle of that of Gunter. From the mathematical construction of the scale, it not only serves the same purpose as other tables of equivalents, but in many instances supersedes the necessity of calculation. Thus, by inspecting the common table of equivalents, we learn that 87 parts, omitting the fraction, or one equivalent of sulphate of potassa, contain 40 parts of sulphuric acid and 47 of potassa; but recourse must be had to calculation, when it is wished to determine the quantity of acid or alkali in any other quantity of the salt. This knowledge, on the contrary, is obtained directly by means of the scale of chemical equivalents. For example, on pushing up the slide until 100 marked upon it is in a line with the name sulphate of potassa on the fixed part of the scale, the numbers opposite to the terms sulphuric acid and potassa will give the precise quantity of each contained in 100 parts of the compound. In the original scale of Dr. Wollaston, oxygen is taken as the standard of comparison, but hydrogen may with equal propriety be selected for this purpose; and scales of this kind have been constructed by Dr. L. C. Beck of New York, and Prof. Henry of Princeton, New Jersey, then associated together.

ATOMIC THEORY.

336. The preceding laws of combination rest upon the immovable basis of facts which have been settled by numerous accurate and decisive experiments; and indeed, the laws themselves, as they are called, are only the enunciations of these facts. The atomic theory was proposed by Dalton the discoverer of the preceding laws, to account for these facts.

Two opposite opinions have long existed concerning the ultimate elements of matter. It is supposed, according to one party, that every particle of matter, however small, may be divided into smaller portions, provided our instruments and organs were adapted to the operation. Their opponents contend, on the other hand, that matter is composed of certain ultimate particles or molecules, which by their nature are indivisible, and are hence termed *atoms* (from *α*, *not*, and *τεμνειν*, *to cut.*) These opposite opinions have from time to time been keenly contested, and with variable success, according to the acuteness and ingenuity of their respective champions. But it was at last perceived that no positive data existed capable of deciding the question, and its interest, therefore, gradually declined. The progress of modern chemistry has revived the general attention to this controversy, by affording a far stronger argument in favor of the atomic constitution of bodies than was ever advanced before, and one which is almost irresistible. We have only, in fact, to assume with Dalton, that all bodies are composed of ultimate atoms, the weight of which is different in different kinds of matter, and we explain at once the foregoing laws of chemical union; and this mode of reasoning is in the present case almost decisive, because the phenomena do not appear explicable on any other supposition.

337. According to the atomic theory, every compound is formed of the atoms of its constituents. An atom of A may unite with one, two, three, or more atoms of B. Thus, supposing water to be composed of one atom of hydrogen and one atom of oxygen, binoxide of hydrogen will consist of one atom of hydrogen and two atoms of oxygen. If carbonic oxide is formed of one atom of carbon and one atom of oxygen, carbonic acid will consist of one atom of carbon and two atoms of oxygen.

If, in the compounds of nitrogen and oxygen enumerated above (332), the first or protoxide consist of one atom of nitrogen and one atom of oxygen, the four others will be regarded as compounds of one atom of nitrogen to two, three, four, and five atoms of oxygen. From these instances it will appear that the law of multiple proportions is a necessary consequence of the atomic theory. There is also no apparent reason why two or more atoms of one substance may not combine with two, three, four, five, or more atoms of another; but, on the contrary, these arrangements are necessary in explanation of the not unfrequent occurrence of half equivalents, as formerly stated. Such combinations will also account for the complicated proportion noticed in certain compounds, especially in many of those belonging to the animal and vegetable kingdoms.

338. In consequence of the satisfactory explanation which the laws of chemical union receive by means of the atomic theory, it has become customary to employ the term *atom* in the same sense as combining proportion or equivalent. For example, instead of describing water as a compound of one equivalent of oxygen and one equivalent of hydrogen, it is said to consist of one atom of each element. In like manner, sulphate of potassa is said to be formed of one atom of sulphuric acid and one atom of potassa; the word in this case denoting, as it were, a compound atom, that is, the smallest integral particle of the acid or alkali,—a particle which does not admit of being divided, except by the separation of its elementary or constituent atoms. The numbers expressing the proportions in which bodies unite must likewise indicate, consistently with this view, the relative weight of atoms; and accordingly, these numbers are often called *atomic weights*. Thus, as water is composed of 8 parts of oxygen and 1 of hydrogen, it follows, on the supposition of water consisting of one atom of each element, that an atom of oxygen must be eight times as heavy as an atom of hydrogen. If carbonic oxide be formed of an atom of carbon and an atom of oxygen, the relative weight of their atoms is as 6.12 to 8; and, in short, the chemical equivalents of all bodies may be considered as expressing the relative weights of their atoms.

The foregoing argument in favor of the atomic constitution of matter, though in itself strong, derives much support from other considerations connected with crystalization, which, however, are too theoretical to be here introduced.

If this theory is considered as resting on a sufficient foundation, the appropriateness of the terms binary, ternary, quaternary, &c., applied to compounds composed of two, three, &c., atoms, by Dalton, will be at once evident.

CHEMICAL SYMBOLS.

339. The impracticability in many cases of contriving convenient names expressive of the constitution of chemical com-

pounds, especially of minerals, suggested the employment of symbols as an abbreviated mode of denoting the composition of bodies. A set of symbols was, therefore, some time ago proposed by Berzelius, which has been almost universally adopted; and cannot be omitted even in an elementary work. Combined according to rules agreed upon to express the various chemical relations of the substances they represent, they constitute *Chemical Formulæ.*

340. The initials of the Latin names of the simple substance are adopted for their symbols, but as several substances have the same initials, the distinction is made by means of an additional letter. Thus B stands for boron; Ba, barium; Bi, bismuth; C for carbon; Cu (from *cuprum*) for copper, &c. On the next page will be found a table representing the symbols of all known simple substances, with their atomic weights.

These symbols indicate a single equivalent of the substances they respectively represent; and to indicate two, three, or more equivalents, a figure is placed a little below the symbol at the right. For instance, S signifies a single eq. of sulphur, S_2, S_3, &c., two, three, &c., eq., and O_4, C_5, four eq. of oxygen, five eq. of carbon, &c. Two or more symbols placed side by side imply that the substances they represent are combined; as S_2O_5, which is the symbol for hyposulphuric acid, and indicates that 2 eq. of sulphur and 5 of oxygen are combined to form an equivalent of this compound. To represent several equivalents of a compound, a figure is placed at the left, which affects all the letters coming after it to the first stop or sign of addition. Thus $2S_2O_5$ signifies two equivalents of hyposulphuric acid. So $H_6C_4O_2$ is the symbol for an eq. of alcohol, and $3H_6C_4O_2$ for 3 eq. of this substance.

A comma placed between two symbols, signifies that they are combined, and is much used in the symbols of complex compounds. Thus, NO_5 is the symbol for nitric acid, and KO that for potassa, while NO_5, KO signifies an eq. of nitrate of potassa. When two salts or other very complex compounds are combined, the sign + is often used. Thus, KO, SO_3 is the symbol for sulphate of potassa, and HO, SO_3, that for common hydrated sulphuric acid; and $KO, SO_3 + HO, SO_3$ signifies the compound formed by the union of the two. But, generally, this sign is used only in cases where an inferior degree of affinity prevails, or where substances are only in a state of mixture.

341. The above explanation of the use of these symbols is in accordance with the most approved usage at the present time, but in many authors slight modifications of it are employed. From the frequent occurrence of a double atom, a symbol has been adopted to designate it, which consists simply in drawing a dash across or under the symbol of the substance. Thus $\cancel{H}$ or $\underline{H}$ signifies 2H, and $\cancel{P}$ or $\underline{P}$ signifies 2P.

So chemical formulæ are sometimes simplified, especially those for ve complex compounds, by denoting degrees of oxydizement by dots placed over the symbols of the elementary substances. Thus, the symbols for potassa, lime, and baryta, become $\dot{\mathrm{K}}$, $\dot{\mathrm{Ca}}$, and $\dot{\mathrm{Ba}}$; and that for nitrate of potassa $\dot{\mathrm{K}}+\overset{.::}{\mathrm{N}}$ or $\dot{\mathrm{K}}\overset{.::}{\mathrm{N}}$. Inverted commas placed in a similar manner over the symbols of the elementary substances, indicate sulphurets of those elements.

Certain compounds, for the sake of brevity, are often denoted by single symbols, in the same manner as the elements; thus an equivalent of water, ammonia, and cyanogen, are sometimes expressed Aq., and Am., and Cy.

A very great advantage derived from the use of these symbols, is the facility they afford in comprehending chemical changes, numerous instances of which will occur in the progress of this work. We will refer now only to the instance of double decomposition on page 121, of carbonate of ammonia and hydrochlorate of lime. Thus, NH^3, CO^2, by interchange of elements with CaO, HCl, will produce CaO, CO^2, and NH^3, HCl, by which we perceive, at a single glance of the eye, that the elements in both cases are the same, as well as the manner in which they were combined, both before and after mutual decomposition.

The following table exhibits the symbols and equivalents of fifty-five simple substances. One or two others have been discovered, but little is yet known with regard to them.

Table of Chemical Symbols and Equivalents of Elementary Substances.

Elements.	*Symbols.*	*Equiv.*	*Elements.*	*Symbols.*	*Equiv.*
Aluminum	Al	13.7	Mercury (Hydrargyrum)	Hg	202.
Antimony (Stibium)	Sb	64.6	Molybdenum	Mo	47.7
Arsenic	As	37.7	Nickel	Ni	29.5
Barium	Ba	68.7	Nitrogen	N	14.15
Bismuth	Bi	71	Osmium	Os	99.7
Boron	B	10.9	Oxygen	O	8.
Bromine	Br	78.4	Palladium	Pd	53.3
Cadmium	Cd	55.8	Phosphorus	P	15,7
Calcium	Ca	20.5	Platinum	Pt	96.8
Carbon	C	6.12	Potassium (Kalium)	K	39.15
Cerium	Ce	46.	Rhodium	R	52.2
Chlorine	Cl	35.42	Selenium	Se	39.6
Chromium	Cr	28.	Silicon	Si	22.5
Cobalt	Co	29.5	Silver (Argentum)	Ag	108.
Columbium (Tantalum)	Ta	185.	Sodium (Natriun)	Na	23.3
Copper (Cuprum)	Cu	31.6	Strontium	Sr	43.8
Fluorine	F	18.68	Sulphur	S	16.1
Glucinum	G	26.5	Tellurium	Te	64.2
Gold (Aurum)	Au	199.2	Thorium	Th	59.6
Hydrogen	H	1.	Tin (Stannum)	Sn	57.9
Iodine	I	126.3	Titanium	Ti	24.3
Iridium	Ir	98.8	Tungsten (Wolfram)	W	99.7
Iron (Ferrum)	Fe	28.	Vanadium	V	68.5
Lanthanum	La		Uranium	U	217.
Lead (Plumbum)	Pb	103.6	Yttrium	Y	32.2
Lithium	L	6.4	Zinc	Zn	32.3
Magnesium	Mg	12.7	Zirconium	Zr	33.7
Manganese	Mn	27.7			

Some English writers, and Hare, in this country, have adopted Po and So, instead of K and Na, as the symbols of potassium and sodium.

342. *Isomeric Bodies.*—This term has been applied to those bodies which are composed of the same elements united in the same proportion, but are possessed of distinct properties. The term is derived from ισος, *equal*, and μερος, *part*, in allusion to the equality of their ingredients.

343. Though bodies of this class have the same ultimate composition, in all their chemical relations they may differ as widely as substances which have not a single element in common. Generally, their equivalents are different. Thus, olefiant gas is composed of a single equivalent of carbon and hydrogen, and paraffine, when analyzed, is found to contain these elements united in the same ratio. The former is distinguished for the variety of its reactions with other substances, while the latter, which is solid, is not acted upon by the strongest acids. The equivalent of olefiant gas is 14.24; but that of paraffine is not known.

344. The discovery of isomerism was quite unexpected, but it is entirely consistent with the usual theories of chemical union. Thus, sulphuric acid is a compound of one equivalent of sulphur, and three eq. of oxygen, but these ingredients may be combined as SO^3, $SO+O^2$, SO^2+O: or, in other words, there may be three substances, composed of these elements, united in the same ratio.

SECTION IV.

CRYSTALOGRAPHY.

345. The particles of liquid and gaseous bodies, as they unite to form solids, sometimes cohere together in an indiscriminate manner, and give rise to irregular, shapeless masses; but more frequently they attach themselves to each other in a certain order, so as to constitute solids possessed of a regularly limited form. The process by which such a body is produced is called *crystalization*; the solid itself is termed a *crystal*; and the science, the object of which is to determine and classify the forms of crystals, is *crystalography*.

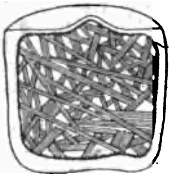
346. Most substances crystalize under favorable circumstances. The condition by which the process is peculiarly favored is the slow and gradual change of a fluid into a solid, the arrangement of the particles being at the same time undisturbed by motion. This is exemplified during the slow cooling of a fused mass of sulphur or bismuth, or the spontaneous evaporation of a saline solution; and the origin of the numerous crystals, which are found in the mineral kingdom, may be ascribed to the influence of the same cause.

347. All substances are limited in the number of their crystaline forms. Thus, calcareous spar crystalizes in rhombohedrons, fluor spar in cubes, and quartz in six-sided pyramids; and these forms are so far peculiar to those substances, that

fluor spar never crystalizes in rhombohedrons or six-sided pyramids, nor calcareous spar or quartz in cubes. Crystaline form may, therefore, serve as a ground of distinction between different substances. It is accordingly employed by mineralogists for distinguishing one mineral species from another; and it is very serviceable to the chemist, being an important physical character of many substances.

348. The crystalization of substances may be effected by several processes. If the substance is more soluble at high than at low temperatures, by making a saturated boiling solution, and allowing it to cool slowly, a portion of crystals will be obtained; if it is equally soluble at all temperatures, the same effect will be produced by the slow evaporation of the solvent. Insoluble substances may often be crystalized by slow cooling from fusion. Thus, if a quantity of sulphur is melted and allowed to cool slowly, upon breaking the crust and pouring out all that remains liquid, a mass of crystals will be found within, shooting in every direction, as represented in fig. 50.

Fig. 50.



The crystalization of many substances, as sulphur, corrosive sublimate, iodine, &c., may also be produced by sublimation.

349. Even in solids, crystalization sometimes takes place. Copper wire which has been long kept is said often to lose its tenacity in consequence of cubic crystals of the metal gradually forming in it. When sugar is melted and allowed to cool, it forms a hard, transparent mass; but by keeping some time it gradually becomes opaque, and exhibits the ordinary white color and crystaline structure of refined sugar. Common "lemon candy," which is usually sold in small flat pieces, an inch wide and four inches long, is beautifully transparent when first formed; but after a few hours crystalization commences in numerous points, and gradually extends through the mass, which now becomes opaque; and at the same time its flavor is much improved.

350. Many substances in crystalizing absorb a large quantity of water, called their *water of crystalization*, which is essential to the existence of the crystals. It sometimes amounts to half their weight. When exposed to the air, the water often evaporates and the crystals fall to powder. They are then said to *effloresce*. Glauber's salt is a noted instance of this.

351. In describing crystals we have frequent occasions to speak of the *faces*, *edges*, and *solid* and *plane angles*. The faces are the planes which terminate the solid in every direction; and the union or junction of any two of them forms an edge A plane angle is formed in a plane by the meeting of two lines, but a solid angle is formed by the meeting of three or more plane angles.

Lines connecting similar parts of crystals diagonally opposite are called *axes*. Usually, these axes connect opposite solid angles or the centres of opposite faces, but sometimes lines uniting the middle points of opposite edges are so termed.

352. The forms of crystals are exceedingly diversified; and are divided into primary and secondary. This distinction is

founded on the fact, that the same substance frequently assumes different forms, which, however, except in cases of dimorphism, are geometrically allied to each other, and may all, by means hereafter to be explained, be reduced to the same.

353. *Primary Forms.*—The number of primary forms is fifteen, and may be divided into three classes of PRISMS, OCTOHEDRONS, and DODECAHEDRONS. The prisms are all four-sided but one, which is six-sided, and is called the *hexagonal prism.* The four-sided prisms may be again subdivided into the *right prisms*, the lateral edges of which are perpendicular to the base, and the *oblique prisms*, the lateral edges of which are inclined to the base.

1. *Right Prisms.*

Base a square; lateral planes equal to basal	*Cube.*
Base a square; lateral planes not equal to basal	*Right Square Prism.*
Base a rectangle	*Rt. Rectanglar P.*
Base a rhombus	*Rt. Rhombic Pr.*
Base a rhomboid	*Rt. Rhomboidal Pr.*

2. *Oblique Prisms.*

Base a rhombus; lateral planes equal to basal,	*Rhombohedron.*
Base a rhombus; lateral planes not equal to basal	*Ob. Rhombic Prism.*
Base a rectangle	*Ob. Rectangular Pr.*
Base a rhomboid	*Ob. Rhomboidal Pr.*

There are four octohedrons, also named from their bases. The octohedron is said to be in position when its base, with reference to which it is named, is horizontal.

Base a square; faces equilateral triangles	*Regular Oct.*
Base a square; faces isosceles triangles	*Square Oct.*
Base a rectangle	*Rectangular Oct.*
Base a rhombus	*Rhombic Oct.*

The rhombic dodecahedron is the only primary solid of this form.

The following table from Dana's Mineralogy exhibits, in a condensed form, the relations of the several primary forms:

PRIMARY FORMS.

PRISMS.	base six-sided				*Hexagonal Prism.*
	base four sided.	right.	lateral planes equal to basal		*Cube.*
			lateral planes not equal to basal	base a square	*Rt. Square Pr.*
				base a rectangle,	*Rt. Rectangular Pr.*
				base a rhombus	*Rt. Rhombic Pr.*
				base a rhomboid,	*Rt. Rhomboidal. Pr.*
		oblique.	lateral planes equal to basal		*Rhombohedron.*
			lateral planes not equal to basal.	base a rhombus,	*Ob. Rhombic Pr.*
				base a rectangle,	*Ob. Rect'lar. Pr.*
				base a rhomboid,	*Ob. Rhom'dal Pr*

OCTOHEDRONS.	faces equilateral		*Regular Octohedron.*
	faces not equilateral	base a square	*Square Oct.*
		base a rectangle	*Rectangular Oct.*
		base a rhombus	*Rhombic Oct.*
DODECAHEDRON			*Rhombic Dodecahedron.*

In giving a more particular description of these solids, some advantage may be gained by keeping distinctly in view the division proposed above (353).

I. PRISMS.

1. *Right Prisms.*

354. In which the lateral edges are all perpendicular to the plane of the base.

Fig. 51.

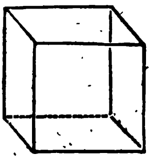
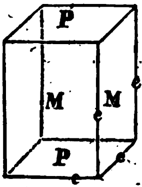


Fig. 52.



1. The cube, figure 51, is a solid bounded by six equal square faces. All its plane angles are right angles.

2. The right square prism, figure 52, is also a six-sided solid, and all its plane angles are right angles, but it differs from the cube, in that the lateral faces M are rectangles, while the bases P are squares. The basal edges *e* are of course equal to each other, but the lateral edges *e*, though equal to each other, may be either greater or less than the basal.

3. The right rectangular prism has six sides, and right angles, but its adjacent lateral faces MM, fig. 52, differ from each other as well as from the bases P. Its faces are in fact all rectangles. No two of its dimensions, of course, are equal.

Fig. 53.

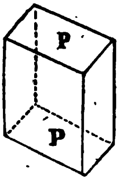
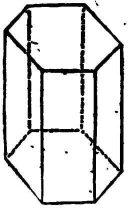


Fig. 54.



4. The right rhombic prism is the same as the right square prism, except that its bases P, fig. 53, are rhombuses.

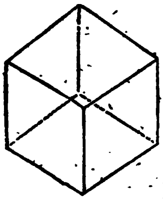
5. The right rhomboidal prism, differs from the right rhombic prism only in its bases, which are parallelograms instead of rhombuses.

6. The hexagonal prism, figure 54, is a solid bounded by six lateral planes, which are rectangles, and two hexagonal bases. The angles of the bases, and of course the inclination of the lateral faces to each other, are 120°.

2. *Oblique Prisms,*

In which the lateral edges are not at right angles to the plane of the base.

Fig. 55.



7. The rhombohedron, figure 55, is bounded by six equal rhombic faces. It differs from the cube, in that none of its adjacent faces are at right angles to each other.

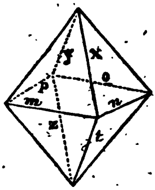
8. In the oblique rhombic prism the bases are rhombuses and the lateral faces parallelograms.

9. The oblique rectangular prism has its bases rectangles, and its lateral planes parallelograms.

10. The oblique rhomboidal prism is a solid bounded by six rhomboids or parallelograms. It differs from the right rhomboidal prism, in having its lateral edges inclined to the plane of the base.

II. OCTOHEDRONS.

Fig. 56.



11. The regular octohedron, figure 56, is contained under eight equilateral triangles; and consequently all its plane angles are 60°. A section, as *mnop*, or *xyzt*, made through any four of its edges, will be a square.

12. The square octohedron, or, as it is sometimes called, the octohedron with a square base, is bounded by eight equal isosceles triangles. The base *mnop*, fig. 56, is a square, which however will not be the case with a section made through any other of its edges, as *xyzt*.

13. The rectangular octohedron is limited by eight isosceles triangles also, but they constitute two classes of four each, which are similar. The base *mnop*, is a rectangle, but the angles of a section made by passing a plane through any other four edges, will be oblique.

14. The rhombic octohedron *aa*, figure 57, is contained under eight faces, which are similar scalene triangles. The base *bbbb* is a rhombus.

Fig. 57.

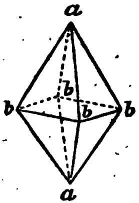
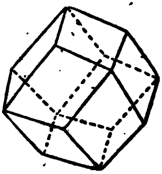


Fig. 58.



III.—DODECAHEDRON.

15. The rhombic dodecahedron, fig. 58, is bounded by twelve similar rhombic faces, which incline to each other at an angle of 120 degrees.

Some of the above forms are very seldom seen, as the oblique rectangular prism, which occurs only in a few artificial salts.

355. *Secondary Forms.*—The secondary forms are very numerous; indeed, the number is unlimited.

They are formed from the primary forms by abstraction of the angles or edges, which is called a replacement of the angle or edge. This replacement may be by a single plane, or by two or more planes. The plane is said to be a *tangent plane*, when it is equally inclined to the two primary faces, which form an edge, or to all the planes which unite to form a solid angle.

Fig. 59.

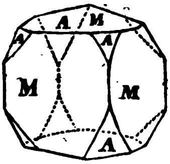
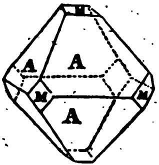


Fig. 60.



The production of secondary forms from the primaries will be best seen by referring to a few instances. Figure 59 represents the cube with all its solid angles replaced by tangent planes, and figure 60 represents the same with the replacements considerably larger, so that the primary faces M are nearly obliterated; but when they disappear, it will evidently pass into the form of the regular octohedron.

Fig. 61.

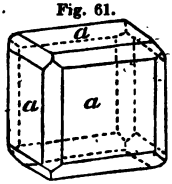
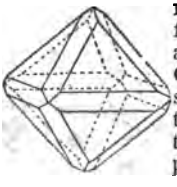


Fig. 61 represents a cube with all its edges replaced by tangent planes; but if the replacement should be continued, till the faces *aaa* of the cube entirely disappear, the rhombic dodecahedron, fig. 58, will result.

Figure 60 may be considered as a regular octohedron, with its six solid angles truncated, and figure 59, the same, with the process of replacement carried still farther. If the replacement is continued till the faces A of the octohedron disappear, we shall evidently have a cube. The right square prism and square octohedron evidently sustain to each other the same relation.

Fig. 62.



The regular octohedron, with all its edges replaced by tangent planes, is represented in fig. 62. This replacement, if continued, would also result in the rhombic dodecahedron.—Other secondary forms may result from these same primaries, by different replacements of the edges and angles, but they cannot be noticed here, nor the thousands which may be produced from the other primary forms.

Crystals are generally more or less cleaveable, that is, capable of division by natural joints. In the primary forms, this takes place, with more or less facility, in planes parallel to all the faces, but, in the secondary forms, cleavage generally produces a replacement of some of the angles or edges.

From the manner in which the secondary forms are derived from the primaries, it will be seen that each primitive form has a series of secondaries peculiar to itself, which is called a *system of crystalization.* There are, therefore, as many systems of crystalization as there are primary forms.

Now all crystals must belong to one of these systems; and all crystals of the same substance, however different in form, it is found, except in the case of dimorphous bodies, to be hereafter noticed, belong to the same system. There are known more than six hundred forms of the crystals of carbonate of lime, but all may be reduced to the rhombohedron, which is its primary form.

356. *Isomorphism.*—This term (from ισος, *equal*, and μορφη, *form*,) is applied to designate the new branch of science laid open by the discovery of Mitscherlich, that certain substances have the property of assuming the same crystaline form, and may be substituted for each other in combination without affecting the external characters of the compound. Thus alum is a compound of ter-sulphate of alumina and sulphate of potassa; but the alumina, it is found, may be entirely replaced by the peroxide of iron, and still the salt will retain the same form, taste, and other properties of common alum. It is generally of a pink tint, but often is perfectly colorless. So also, ammonia may be made to take the place of the potassa without changing the general properties of the salt. Alumina and peroxide of iron are therefore isomorphous, as are also potassa and ammonia.

357. Of these isomorphous bodies, several distinct groups have been described. One of the most instructive of these includes the salts of arsenic and phosphoric acid. Thus, the neutral phosphate and biphosphate of soda have exactly the same form as the arseniate and biarseniate of soda; and phosphate and biphosphate of ammonia, correspond to arseniate and biarseniate of ammonia. Each arseniate has a corresponding phosphate, possessed of the same form, containing the same number of equivalents of acid, alkali, and water of crystalization, and differing in fact in nothing, except that one series contains arsenic and the other an equivalent quantity of phosphorus.

358. Numerous other groups of isomorphous substances have been determined, some of which are simple and others compound. Two or three only can be introduced.

1.

Gold	Au
Silver	Ag

2.

Magnesia	MgO
Protoxide of Iron	FeO
" Manganese	MnO
" Copper	CuO
" Cobalt	CoO
" Nickel	NiO
" Zinc	ZnO
" Cadmium	CdO

3.

Sulphuric Acid	SO_3
Telluric "	TeO_3
Selenic "	SeO_3
Chromic "	CrO_3
Manganic "	MnO_3

4.

Perchloric Acid	ClO_7
Permanganic "	Mn_2O_7
Periodic "	IO_7

359. The salts formed by the union of the several protoxides constituting the second group with acids, are always isomorphous when the degree of saturation and quantity of water of crystalization are the same. So, acids of the third and fourth group combine with bases and form isomorphous salts, when containing the same proportion of base and water of crystalization.

360. Compound isomorphous substances generally possess precisely the same atomic constitution, that is, they generally contain the same number of equivalents of each of the elements of which they are composed, but this is not always the case. In the fourth group, above given, it will be observed, one of the substances contains 2 eq. of one of its ingredients united to 7 eq. of oxygen, while the others contain each only 1 eq. in combination with the same quantity of oxygen.

Isomorphous substances often have many very close points of resemblance, quite independently of form; thus, they are equally fusible, volatile, &c., and act towards other reagents much in the same manner; but this is by no means always the case. Sometimes they are found entirely dissimilar in every respect except their form.

361. Isomorphous substances, owing doubtless to their various points of resemblance, crystalize together with great readiness, and are separated from each other with difficulty. A mixture of the sulphates of the protoxides of copper and iron yields crystals which have the same quantity of water of crystalization, (6 equivalents,) and the same form as green vitriol, though they may contain a large quantity of copper. The sulphates of the protoxides of zinc and copper, of copper and magnesium, of copper and nickel, of zinc and manganese, and of magnesium and manganese, crystalize together, contain 6 equivalents of water, and have the same form as green vitriol, without containing a particle of iron. These mixed salts may be crystalized over and over again, without the ingredients being separated from each other, just as it is extremely difficult to purify alum from sesquioxide of iron, with which alumina is isomorphous. In these instances the isomorphous salts do not occur in definite proportions: they are not chemically united as double salts, but merely crystalize together.

362. *Dimorphism.*—This term is applied to that peculiarity of certain substances, by which they present entirely distinct crystalizations under different circumstances. Thus sulphur is capable of yielding crystals which must be referred to two separate systems of crystalization, depending upon the circumstances under which the process takes place; and carbonate of lime in calcareous spar, and arragonite, belong to different systems, the former having for its primary form the rhombohedron, and the latter the right rhombic prism. Crystals of sulphate of zinc change their form merely by being gradually heated.

A substance, in its dimorphous conditions, frequently presents a great difference of chemical properties as well as of form. Thus bisulphuret of iron is dimorphous; and when crystalized in the form of the cube it is very permanent, resisting entirely the action of the air and moisture, but when in its right rhombic form it gradually absorbs oxygen from the air, and is converted into sulphate of iron.

CHAPTER II.

NON-METALLIC ELEMENTS

SECTION I.

OXYGEN.

Symbol O; Equivalent 8.

363. Oxygen gas was discovered by Priestley in 1774, and by Scheele a year or two after, without previous knowledge of Priestley's discovery. Several appellations have been given to it. It was named *dephlogisticated air* by Priestley, *empyreal air* by Scheele, and *vital air* by Condorcet. The name it now bears, derived from the Greek words οξυς, *acid*, and γενναω, *to generate*, was proposed by Lavoisier, who considered it the sole cause of acidity.

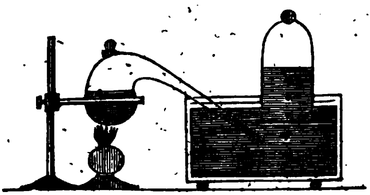
364. Oxygen gas may be obtained from several sources. The peroxides of manganese, lead, and mercury, and nitrate, and chlorate of potassa, yield it in large quantities when they are exposed to a red heat. The substances commonly employed for the purpose are peroxide of manganese and nitrate and chlorate of potassa. From the peroxide of manganese it may be procured in two ways; either by heating it to redness in a gun-barrel, or in a retort of iron or earthenware; or by putting it in fine powder into a flask with about an equal weight of concentrated sulphuric acid, and heating the mixture by means of a lamp.

To understand the theory of these processes, it is necessary to bear in mind the composition of the three following oxides of manganese:—

	Manganese.	*Oxygen.*	
Protoxide	27.7 or 1 equiv.	+ 8	=35.7
Sesquioxide	27.7	+12	=39.7
Peroxide	27.7	+16	=43.7

On applying a red heat to the last, it parts with half an equivalent of oxygen, and is converted into the sesquioxide. Every 43.7 grains of the peroxide will therefore lose, if quite pure, 4 grains of oxygen, or nearly 12 cubic inches; and one ounce will yield about 128 cubic inches of gas. The action of sulphuric acid is different. The peroxide loses a whole equivalent of oxygen, and is converted into the protoxide which unites with the acid, forming a sulphate of the protoxide of manganese. Every 43.7 grains of peroxide must consequently yield 8 grains of oxygen and 35.7 of protoxide, which by uniting with one equivalent (40.1) of the acid, forms 75.8 of the sulphate. The accompanying figure will serve to illustrate the apparatus used in this process for preparing oxygen.

Fig. 63.



365. The gas obtained from peroxide of manganese, though hardly ever quite pure, owing to the presence of iron, carbonate of lime, and other earthy substances, is sufficiently good for ordinary purposes. It yields a gas of better quality, if previously freed from carbonate of lime by dilute hydrochloric or nitric acid; but when oxygen of great purity is required, it is better to obtain it from chlorate of potassa. For this purpose, the salt should be put into a retort of green glass, or of white glass made without lead, and be heated nearly to redness. It first becomes liquid, though quite free from water, and then, on increase of heat, is wholly resolved into pure oxygen gas, which escapes with effervescence, and into a white compound, called chloride of potassium, which is left in the retort.

The following formula clearly explains the changes that take place, $KO, ClO_5 = KCl + 6O$. It will thus be seen that the oxygen is derived in part from the potassa, but chiefly from the chloric acid. From 122.57 grains of the salt, 48 grs. or about 161 cubic inches of pure oxygen may be obtained.

The best method to obtain it for ordinary purposes, is to heat to redness nitrate of potassa in an iron bottle. The salt first becomes liquid, and is then gradually decomposed, yielding at first very pure oxygen, especially if the heat is not permitted to rise too rapidly. The very first portions that come over should be rejected as being usually mixed with atmospheric air and carbonic acid derived from combustible matter contained in the salt; and if at any time the gas should begin to form too rapidly, the heat must be instantly checked, as binoxide of nitrogen and other gases are beginning to pass over, and will render the oxygen unfit for use. A mercury flask with a gun-barrel screwed into it for a neck answers admirably well for this purpose; or for collecting small quantities of the gas, a gun-barrel alone is sufficient.

The changes that occur by this process are illustrated by the following formula: $KO, NO_5 = KO, NO_3 + 2O$.

366. Oxygen gas is colorless, has neither taste nor smell, is not chemically affected by the imponderables, refracts light very feebly, and is a non-conductor of electricity. It is the most perfect negative electric that we possess, always appearing at the positive electrode when any compound which contains it is electrolized. It emits light, as well as heat, when suddenly and forcibly compressed; but this is solely owing to the combustion of the oil with which the compressing tube is lubricated.

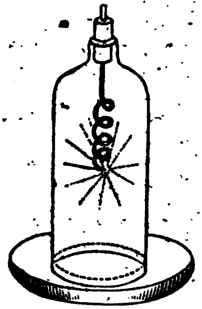
Oxygen gas is heavier than atmospheric air, but its exact specific gravity seems not to be fully settled. Adopting 1.10 as its correct specific gravity, 100 cubic inches, when the thermometer is at 60° and the barometer stands at 30 inches, would weigh 34.19 grains.

367. Oxygen gas is very sparingly absorbed by water, 100 cubic inches of that liquid dissolving only 3 or 4 of the gas. It is neither acid nor alkaline, nor does it evince a disposition to unite directly either with acids or alkalies. It has a very powerful attraction for most simple substances; and there is not one of them with which it may not be made to combine. The act of combining with oxygen is called *oxydation*, and bodies which have united with it are said to be *oxydized*. The compounds so formed are divided by chemists into acids and oxides. The former division includes those compounds which possess the general properties of acids; and the latter comprehends those which not only want that character, but of which many are highly alkaline, and yield salts by uniting with the acids. The phenomena of oxydation are variable. It is sometimes produced with great rapidity, and with evolution of heat and light. Ordinary combustion, for instance, is nothing more than rapid oxydation; and all inflammable or combustible substances derive their power of burning in the open air from their affinity for oxygen. On other occasions it takes place slowly, and without any appearance either of heat or light, as is exemplified by the rusting of iron when exposed to a moist atmosphere. Different as these processes may appear, oxydation is the result of both; and both depend on the same circumstances, namely, the presence of oxygen in the atmosphere.

368. All substances that are capable of burning in the open air, burn with far greater brilliancy in oxygen gas. A piece of wood, on which the least spark of light is visible, bursts into flame the moment it is put into a jar of oxygen; lighted charcoal emits beautiful scintillations; and phosphorus burns with

so powerful and dazzling a light that the eye cannot bear its impression. Even iron and steel, which are not commonly ranked among the inflammables, undergo rapid combustion in oxygen gas.

Fig. 64.



The combustion of iron and steel is effected by introducing it in the form of wire or thin slips into a vessel of the gas, as shown in figure 64. The combustion is commenced by attaching to the lower extremity a piece of spunk or other combustible, which is ignited the moment it is introduced into the gas.

369. The changes that accompany these phenomena are no less remarkable than the phenomena themselves. When a lighted taper is put into a vessel of oxygen gas, it burns for a while with increased splendor; but the size of the flame soon begins to diminish, and if the mouth of the jar be closed, the light will in a short time disappear entirely. The gas has now lost its characteristic property; for a second lighted taper, immersed in it, is instantly extinguished. This result is general. The burning of one body in a given proportion of oxygen, unfits it more or less completely for supporting the combustion of another; and the reason is manifest. Combustion is produced by the combination of inflammable matter with oxygen. The quantity of free oxygen, therefore, diminishes during the process, and is at length nearly or quite exhausted. The burning of all bodies, however inflammable, must then cease, because the presence of oxygen is necessary to its continuance. For this reason oxygen gas is called a supporter of combustion. The oxygen often loses its gaseous form as well as its other properties. If phosphorus or iron be burned in a jar of pure oxygen over water or mercury, the disappearance of the gas becomes obvious by the ascent of the liquid, which is forced up by the pressure of the atmosphere, and fills the vessel. Sometimes, on the contrary, the oxygen gas suffers diminution of volume only, or it may even undergo no change of bulk at all, as is exemplified by the combustion of the diamond.

370. The changes experienced by the burning body are equally striking. While the oxygen loses its power of supporting combustion, the inflammable substance lays aside its combustibility. It is then an oxydized body, and cannot be made to burn even by aid of the purest oxygen gas. It has also increased in weight. It is an error to suppose that bodies lose anything while they burn. The materials of our fires and candles do indeed disappear, but they are not destroyed. Although they fly off in the gaseous form, and are commonly lost to us, it is not difficult to collect and preserve all the pro-

ducts of combustion. When this is done with the required care, the combustible matter is always found to weigh more after than before combustion, and the increase in weight is exactly equal to the quantity of oxygen which has disappeared during the process.

371. Oxygen gas is necessary to respiration. No animal can live in an atmosphere which does not contain a certain portion of uncombined oxygen; for an animal soon dies if put into a portion of air from which the oxygen has been previously removed by a burning body. It may, therefore, be anticipated that oxygen is consumed during respiration. If a bird be confined in a limited quantity of atmospheric air, it will at first feel no inconvenience; but as a portion of oxygen is withdrawn at each inspiration, its quantity diminishes rapidly, so that respiration soon becomes laborious, and in a short time ceases altogether. Should another bird be then introduced into the same air, it will die in the course of a few seconds; or if a lighted candle be immersed in it, its flame will be extinguished. Respiration and combustion have, therefore, the same effect. An animal cannot live in an atmosphere which is unable to support combustion; nor, in general, can a candle burn in air which contains too little oxygen for respiration.

372. Though oxygen is necessary to respiration, in a state of purity it is deleterious. When an animal, as a rabbit for example, is supplied with an atmosphere of pure oxygen gas, no inconvenience is at first perceived; but after the interval of an hour or more, the circulation and respiration become very rapid, and the system in general is highly excited. Symptoms of debility subsequently ensue, followed by insensibility; and death occurs in six, ten, or twelve hours. On examination after death, the blood is found highly florid in every part of the body, and the heart acts strongly even after the breathing has ceased.

THEORY OF COMBUSTION.

373. The only phenomena of combustion noticed by an ordinary observer, are the destruction of the burning body, and the development of heat and light; but it has been demonstrated that in addition to these circumstances, oxygen gas invariably disappears, and a new compound, consisting of oxygen and the combustible, is generated. The term *combustion*, therefore, in its common signification, implies the rapid union of oxygen gas and combustible matter, accompanied with heat and light.

But numerous other cases of chemical action are attended with the evolution of light and heat. Thus a burning taper introduced into an atmosphere of chlorine, continues to burn a short time, and phosphorus and several of the metals take fire in it spontaneously. Several of the metals in the state of fine wire or thin leaf burn readily in vapor of sulphur. There being, therefore, no reason why a distinction should be made between these different cases of chemical combination, combustion can be considered as only intense chemical action attended by the evolution of light and heat.

374. For many years prior to the discovery of oxygen gas, the phenomena of combustion were explained on the Stahlian or phlogistic hypothesis. All combustible bodies, according to Stahl, contain a certain principle which he called *phlogiston*, to the presence of which he ascribed their combustibility. He supposed that when a body burns, phlogiston escapes from it; and that when the body has lost phlogiston, it ceases to be combustible, and is then a dephlogisticated or incombustible substance. A metallic oxide was consequently regarded as a simple substance, and the metal itself as a compound of its oxide with phlogiston.

375. On this theory, it is evident, a metal by burning, being deprived of its phlogiston, should decrease in weight. It was known, however, on the contrary, long before the Stahlian theory was relinquished, that the reverse of this takes place, and efforts were made to devise some satisfactory explanation, but of course without avail.

To Lavoisier belongs the honor of overthrowing this long-cherished theory, by showing in the most decisive manner that ordinary combustion and oxydation are essentially the same thing, consisting in the union of the oxygen of the atmosphere with the combustible body. Thus, when an iron wire is consumed in oxygen gas, the oxide of iron formed will always be found to weigh precisely as much as the iron itself, and the oxygen that has disappeared during the process.

Lavoisier also attempted on his theory to account for the evolution of light and heat during combustion, but without success; and the subject at the present time seems but imperfectly understood.

SECTION II.

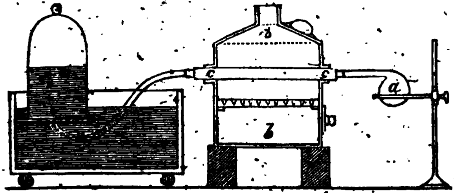
HYDROGEN.

Symbol H; Equivalent 1.

376. THIS gas was formerly termed *inflammable air*, from its combustibility, and *phlogiston*, from the supposition that it was the matter of heat (374); but the name *hydrogen*, from υδωρ, *water*, and γενναω, to *generate*, has now become general. Its nature and leading properties were first pointed out in the year 1766, by Cavendish.

377. Hydrogen gas may be easily procured in two ways. The first consists in passing the vapor of water over metallic iron heated to redness. This is done by putting iron wire into a gun-barrel open at both ends, to one of which is attached a retort containing pure water, and to the other a bent tube. The gun-barrel is placed in a furnace, and when it has acquired a full red heat, the water in the retort is made to boil briskly. The gas which is copiously disengaged as soon as the steam comes in contact with the glowing iron, passes along the bent tube, and may be collected in convenient vessels, by dipping the free extremity of the tube into the water of a pneumatic trough.

Fig. 65.



The arrangement of the apparatus will be seen by figure 65; *a* is the retort containing the water, *bb* furnace with the gun-barrel *cc*, in which are the iron turnings to be heated, and at the left is the receiver to collect the gas as it is formed.

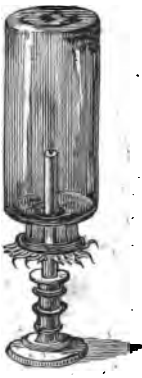
The second and most convenient method consists in putting pieces of iron or zinc into dilute sulphuric acid, formed of one part of strong acid and four or five of water. Zinc is generally preferred. The hydrogen obtained in these processes is not absolutely pure. The gas evolved during the solution of iron has an offensive odor, ascribed to the presence of a volatile oil, which may be almost entirely removed by transmitting the gas through alcohol. The oil appears to arise from some compound being formed between hydrogen and the carbon which is always contained even in the purest kinds of common iron; and it is probable that a little carburetted hydrogen gas is generated at the same time. The zinc of commerce contains sulphur, and almost always traces of charcoal, in consequence of which it is contaminated with hydrosulphuric acid, and probably with the same impurities, though in a less degree, as are derived from iron. A little metallic zinc is also contained in it, apparently in combination with hydrogen. All these impurities, carburetted hydrogen excepted, may be removed by passing the hydrogen through a solution of pure potassa. To obtain hydrogen of great purity, distilled zinc should be employed.

378. Hydrogen is a colorless gas, and refracts light powerfully; and when pure is without odor or taste. It is the lightest body in nature, and is consequently the best material for filling balloons. From its extreme lightness it is difficult to ascertain its precise density by weighing; because the presence of minute

quantities of common air or watery vapor occasions considerable error. It is 16 times lighter than oxygen, an inference derived from the composition of water to be shortly stated: hence 100 cubic inches of hydrogen gas at 60° and 30 inches Bar. should weigh $\frac{1}{16}\times 34.19=2.14$ grains, and that its specific gravity is 0.0689.

It is nearly 15 times lighter than atmospheric air, 140,000 times lighter than mercury, and 220,000 times lighter than platinum.

Fig. 66.



379. Hydrogen is neither acid nor alkaline. It is sparingly absorbed by water, 100 cubic inches of that liquid dissolving about one and a half of the gas. It cannot support respiration; for an animal soon perishes when confined in it. Death ensues from deprivation of oxygen rather than from any noxious quality of the hydrogen, since an atmosphere composed of a due proportion of oxygen and hydrogen gases may be respired without inconvenience. Nor is it a supporter of combustion; for when a lighted candle fixed on wire is passed up into an inverted jar full of hydrogen gas, the light instantly disappears.

380. Hydrogen gas is inflammable in an eminent degree, though, like other combustibles, it requires the aid of a supporter of combustion. Thus, in the experiment above alluded to, as the candle passes into the hydrogen, though it is itself extinguished, the gas is kindled, but burns only where it is in contact with the air. Its combustion, when conducted in this manner, goes on tranquilly, and is attended with a yellowish-blue flame and a very feeble light. The phenomena are different when the hydrogen is previously mixed with a due quantity of air. The approach of flame not only sets fire to the gas near it, but the whole is kindled at the same instant, and a flash of light passes through the mixture, followed by a violent explosion. The best proportion for the experiment is two measures of hydrogen to five or six of air. The explosion is far more violent when pure oxygen is used instead of air, particularly when the gases are mixed together in the ratio of one measure of oxygen to two of hydrogen.

381. Oxygen and hydrogen gases cannot combine at ordinary temperatures, and may, therefore, be kept in a state of mixture without even gradual combination taking place between them. Hydrogen may be set on fire, when in contact with air or oxygen gas, by flame, by a solid body heated to bright redness, and by the electric spark.

382. Spongy platinum also produces the same effect, nearly as readily as the electric spark, provided the gases are pure

and mixed in the proper proportion of one measure of oxygen to two of hydrogen. This discovery was made in 1824 by Doebereiner of Jena. Spongy platinum is prepared by precipitating the nitro-hydrochloric solution platinum by hydrochlorate of ammonia, and igniting the precipitate. Faraday has shown that platinum foil, if *perfectly* clean, will produce the same effect.

It is by means of this spongy platinum that the hydrogen lamp is inflamed. This apparatus consists simply of two glass vessels, so arranged that by the action of dilute sulphuric acid upon a piece of zinc, a quantity of hydrogen is generated and preserved until it is needed, when a jet of it as it escapes is made to fall upon a piece of spongy platinum, by which it is inflamed. The jet of hydrogen, as it issues into the air, mixing with the oxygen, produces the same effect as when the spongy metal is introduced into a vessel filled with the mixed gases.

383. A singular phenomenon, which is best produced by the flame of hydrogen, although not peculiar to it, is the production of musical sounds if an open tube be held over it. The jet of hydrogen, if inflamed as it issues into the air, burns silently and continuously; but on placing a tube over it the oxygen of the air coming in contact with it only from below, the flame is changed into a succession of little explosions of mixed air and gas, and a distinct musical note is produced by the vibrations of the air in the tube.

384. A large quantity of heat is evolved during the combustion of hydrogen gas. The most intense heat that can be produced is caused by the combustion of hydrogen in oxygen gas. Dr. Hare of Philadelphia, who first burned hydrogen for this purpose, collected the gases in separate gasholders, from which a stream was made to issue through tubes communicating with each other, just before their termination. At this point the jet of the mixed gases was inflamed. The effect of the combustion, though very great, is materially increased by forcing the two gases in due proportion into a strong metallic vessel by means of a condensing syringe, and setting fire to a jet of the mixture as it issues. In this state, however, the apparatus should never be used; for as the reservoir is itself full of an explosive mixture, there is great danger of the flame running back along the tube, and setting fire to the whole gas at once. To prevent the occurrence of such an accident, which would most probably prove fatal to the operator, several methods have been devised by Cumming, Wollaston, Gurney, and lately by Hemming, none of which is it necessary here to describe, since, in a case of such danger, they should not be trusted. It was for a time supposed that the invention of the last named gentleman might be relied upon with perfect safety, but a recent explosion in the laboratory of Dr. Webster, of Boston, while using this instrument, shows the need of caution.

A very intense heat may be produced by transmitting a jet of oxygen gas through the flame of a spirit-lamp, or by introducing a jet of oxygen gas into the middle of another jet of hydrogen, or of carburetted hydrogen.

Dr. Hare has recently been able, by means of improvements in his oxy-hydrogen or compound blow-pipe, perfectly to fuse 14½ ounces of platinum at a time.

385. It has already been remarked that hydrogen, in consequence of its extreme lightness, is used for filling balloons, the buoyancy of which it is sometimes necessary to compute. This is readily done in the following manner:—If 100 cubic inches of air weigh 31.01 grains (291), the weight of a cubic foot will of course be 535.85 grains, while the weight of an equal volume of hydrogen (378) will be found to be but 36.98 grains. Now 535.85—36.98=498.87 grs., which is the buoyancy or ascensional force of a cubic foot of the pure gas. But from this we must of course subtract the weight of the balloon itself; and, as in practice, the hydrogen will always be more or less impure, due allowance must be made for it in order to obtain the actual ascensional force. Probably in practice a cubic foot of gas would be found to ascend readily with about 480 grains, or one ounce troy; and therefore to obtain the ascensional force of a balloon, multiply the cubic feet of gas it contains by 480, and divide by 7000, (the number of troy grains in a pound avoirdupois,) which will give the result in avoirdupois pounds, from which subtract the weight of the balloon.

It is said, however, that coal gas, though much heavier than hydrogen, is now much used in balloons in consequence of its being prepared cheaper, the balloon being of course made proportionally larger.

HYDROGEN AND OXYGEN.

386. There are but two known compounds of these two substances, the protoxide and peroxide.

	Hydrogen.	*Oxygen.*	*Equiv.*	*Symbol*
Protoxide of hydrogen or WATER	1 eq.	+ 1 eq.	9	HO
Peroxide	1 eq.	+ 2 eq.	17	HO_2

Protoxide of Hydrogen, or WATER.—Water is the sole product of the combustion of hydrogen gas. For this important fact we are indebted to Cavendish. He demonstrated it by burning oxygen and hydrogen gases in a dry glass vessel; when a quantity of pure water was generated, exactly equal in weight to that of the gases which had disappeared. This experiment, which is the synthetic proof of the composition of water, was afterwards made on a much larger scale in Paris by Vauquelin, Fourcroy, and Seguin. Lavoisier first demonstrated its nature analytically, by passing a known quantity of watery vapor over metallic iron heated to redness in a glass tube. Hydrogen gas was disengaged, the metal in the tube was oxydized, and the weight of the former, added to the increase which the iron had experienced from combining with oxygen, exactly corresponded to the quantity of water decomposed.

387. The exact determination of the proportion in which these substances unite to form water, is a most important

object in chemistry, in consequence of the great range of the affinities which they exercise. It has therefore engaged the attention of some of the ablest experimenters; and it has been satisfactorily determined that 100 parts of pure water consist of 11.1 of hydrogen and 88.9 of oxygen, which is the ratio of 1 to 8.009; or very nearly that of 1 to 8, as above stated.

388. The processes for procuring a supply of hydrogen gas will now be intelligible. The first is the method by which Lavoisier made the analysis of water. It is founded on the fact that iron at a red heat decomposes water, the oxygen of that liquid uniting with the metal, and the hydrogen gas being set free. That the hydrogen which is evolved when zinc or iron is put into dilute sulphuric acid must be derived from the same source, is obvious from the consideration that, of the three substances, iron, sulphuric acid, and water, the last is the only one which contains hydrogen. The product of the operation, besides hydrogen, is sulphate of the protoxide of iron, if iron is used, according to the following formula: $HO+SO_3+Fe=FeO, SO_3+H$.

When zinc is used instead of iron the chemical changes that take place are similar, as follows: $HO+SO_3,+Zn=ZnO, SO_3+H$. An ounce of zinc will yield 676 cubic inches of hydrogen, and an equal quantity of iron, 780.

389. Water is a transparent, colorless liquid, which has neither smell nor taste. It is a powerful refractor of light, conducts heat very slowly, and is an imperfect conductor of electricity. It is slightly compressible by pressure, its absolute diminution for one atmosphere being 51.3 millionths of its volume. The relations of water, with respect to heat, are highly important; but they have already been discussed in the first part of the work. The specific gravity of water is 1, the density of all solid and liquid bodies being referred to it as a term of comparison. One cubic inch at 62° and 30 inches of the barometer, weighs 252.458 grains; so that it is 814 times as heavy as atmospheric air.

390. Water, owing partly to the extensive range of its own affinity, and partly to the nature of its elements, is one of the most powerful agents which we possess. The preparation of hydrogen gas is an example of this; and indeed there are few complex changes, where oxygen and hydrogen are present, which do not give rise either to the production or decomposition of water. But, independently of the elements of which it is composed, it combines directly with many bodies. Sometimes it is contained in a variable ratio, as in ordinary solutions; in other compounds it is present in a fixed definite proportion, as is exemplified by its union with several of the acids, the alkalies, and all salts that contain water of crystalization. These combinations are termed *hydrates*. Thus, concentrated

sulphuric acid is a compound of one equivalent of the real acid and one equivalent of water; and its proper name is *hydrous sulphuric acid*, or *hydrate of sulphuric acid*. The adjunct *hydro* has been sometimes used to signify the presence of water in definite proportion; but it is advisable, to prevent mistakes, to limit its employment to the compounds of hydrogen.

391. The purest water which can be found as a natural product, is procured by melting freshly-fallen snow, or by receiving rain in clean vessels at a distance from houses. But this water is not absolutely pure; for if placed under the exhausted receiver of an air-pump, or boiled briskly for a few minutes, bubbles of gas escape from it. The air obtained in this way from snow water is much richer in oxygen gas that atmospheric air. According to the experiments of Gay-Lussac and Humboldt, it contains 34.8 per cent. of oxygen, and the air separated by ebullition from rain-water contains 32 per cent. of that gas. Other gases are absorbed by it; some of them in large quantities and with great rapidity. All water which has once fallen on the ground, becomes impregnated with more or less earthy or saline matters, and it can be separated from them only by distillation. The distilled water, thus obtained, and preserved in clean, well-stopped bottles, is absolutely pure. Recently boiled water has the property of absorbing a portion of all gases, when its surface is in contact with them; and the absorption is promoted by brisk agitation.

Aq. (from aqua, *water*,) is often used as the symbol for water instead of the one given in the table.

392. *Per or Binoxide of Hydrogen.*—This compound was discovered by Thenard, in the year 1818. The method of forming it is too complicated to be here repeated. It has been obtained only in the liquid form, and when most concentrated possesses a specific gravity of 1.452. It is colorless, transparent, and without odor. Sometimes called oxygenized water.

Though it differs from water only in containing an additional equivalent of oxygen, it acts powerfully upon the skin, producing a prickling sensation, whitening the surface, and destroying the texture, if the application is long continued.

If the temperature is raised as high as 59°, it is decomposed and converted into water and oxygen gas; a sudden elevation of temperature even causes an explosion. It is also decomposed by the action of nearly all the metals, and many of the metallic oxides. Diluted with water or mixed with some acid, it is less liable to decomposition than when pure.

SECTION III.

NITROGEN.

Symbol N; Equivalent 14.15.

393. The existence of nitrogen gas, as distinct from every ther gaseous substance, appears to have been first noticed in he year 1772, by Rutherford, of Edinburgh. Lavoisier discovered in 1775 that it is a constituent part of the atmosphere; and the same discovery was made soon after, or about the same time, by Scheele. Lavoisier called it *azote*, (from *a*, *privative*, and ζωη, *life*,) because it is unable to support the respiration of animals; but the term *nitrogen* has been since applied to it, from the circumstance of its being an ingredient of nitric acid.

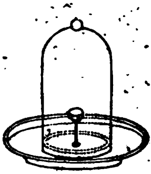


Fig. 67.

394. Nitrogen is most conveniently prepared by burning a piece of phosphorus in a jar full of air, inverted over water. The strong affinity of phosphorus for oxygen enables it to burn till the whole of that gas is consumed. The product of the combustion, phosphoric acid, is at first diffused through the residue in the form of a white cloud; but as this substance is rapidly absorbed by water, it disappears entirely in the course of half an hour. The residual gas is nitrogen, containing a small quantity of carbonic acid and vapor of phosphorus, both of which may be removed by agitating it briskly with a solution of pure potassa. Several other substances may be employed for withdrawing oxygen from atmospheric air. A solution of protosulphate of iron, charged with binoxide of nitrogen, absorbs the oxygen in the space of a few minutes. A stick of phosphorus produces the same effect in twenty-four hours, if exposed to a temperature of 60°. A solution of sulphuret of potassium or calcium acts in a similar manner; indeed, any substance that will serve to absorb oxygen rapidly. It is sometimes found in the water of mineral springs, as at Lebanon, New York.

395. Pure nitrogen is a colorless gas, wholly devoid of smell and taste. It does not change the blue color of vegetables, and is distinguished from other gases more by negative characters than by any striking quality. It is not a supporter of combustion; but, on the contrary, extinguishes all burning bodies that are immersed in it. No animal can live in it; but yet it exerts no injurious action either on the lungs or on the system at large, the privation of oxygen gas being the sole cause of death. It is not inflammable like hydrogen; though, under favorable circumstances, it may be made to unite with oxygen

Water, when deprived of air by ebullition, takes up about one and a half per cent. of it.

Its specific gravity is about 0.97; 100 cubic inches weighing about 30.16 grains.

396. Some doubt has existed with regard to the nature of nitrogen; several chemists, among whom is Berzelius, considering it a compound body: but there seems to be no sufficient reason for this opinion. We therefore rank it among the elementary substances.

NITROGEN AND OXYGEN.

397. The compounds of nitrogen and oxygen are five, exclusive of atmospheric air, concerning which writers do not yet entirely agree, whether to consider it a chemical compound, or only a mixture of those gases.

	By volume.		*By weight.*			
	Nit.	*Oxy.*	*Nit.*	*Oxy.*	*Equiv.*	*Symbols.*
Nitrous oxide	100+	50	1 eq.+	1 eq.	22.15	NO
Nitric oxide	100+	100	1 eq.+	2 eq.	30.15	NO_2
Hyponitrous acid	100+	150	1 eq.+	3 eq.	38.15	NO_3
Nitrous acid	100+	200	1 eq.+	4 eq.	46.15	NO_4
Nitric acid	100+	250	1 eq.+	5 eq.	54.15	NO_5
Atmospheric air	400+	100	2 eq.+	1 eq.		

THE ATMOSPHERE.

398. The earth is everywhere surrounded by a mass of gaseous matter called the atmosphere, which is preserved at its surface by the force of gravity, and revolves together with it around the sun. It is colorless and invisible, excites neither taste nor smell when pure, and is not sensible to the touch unless when it is in motion. It possesses the physical properties of elastic fluids in a high degree. Its specific gravity is unity, being the standard with which the density of all gaseous substances is compared. It is 814 times lighter than water, and nearly 11065 times lighter than mercury. The knowledge of its exact weight is an essential element in many physical and chemical researches, and has been lately determined with very great care by Prout. According to his observations 100 cubic inches of pure and dry atmospheric air, at 60° and 30 B., weigh 31.01 grains (291).

399. The pressure of the atmosphere was first noticed early in the 17th century by Galileo, and was afterwards demonstrated by his pupil Torricelli, to whom science is indebted for the invention of the barometer. Its pressure at the level of the sea is equal to a weight of about 15 pounds on every square inch of surface, and is capable of supporting a column of water 34 feet high, and one of mercury of 30 inches; that is, a column of mercury 1 inch square and 30 inches long has the same weight (nearly 15 pounds) as a column of water of equal base

and 34 feet long, and as a column of air of equal base reaching from the level of the sea to the extreme limit of the atmosphere. By the use of the barometer it was discovered that the atmospheric pressure is variable. It varies according to the elevation above the level of the sea, and on this principle the height of mountains is estimated. Supposing the density of the atmosphere to be uniform, a fall of one inch in the barometer would correspond to 11065 inches, or 922 feet of air; but in order to make the calculation with accuracy, allowance must be made for the increasing rarity of the air, and for various other circumstances which are detailed in works on meteorology. From causes at present not understood, the pressure varies likewise at the same place. On this depends the indications of the barometer as a weather-glass; for observation has fully proved that the weather is commonly fair and calm when the barometer is high, and usually wet and stormy when the mercury falls.

400. Atmospheric air is highly compressible and elastic, so that its particles admit of being approximated to a great extent by compression, and expand to an extreme degree of rarity when the tendency of its particles to separate is not restrained by external force. The volume of air and all other gaseous fluids, so long as they retain the elastic state, is inversely as the pressure to which they are exposed. Thus a portion of air which occupies 100 measures when compressed by a force of one pound, will be diminished to 50 measures when the pressure is doubled, and will expand to 200 measures when the compression is equal to half a pound. But those gases which are susceptible of condensation by pressure into the liquid form, as the pressure approaches this point, vary from the law, the volume diminishing more rapidly than this would indicate.

401. The atmosphere is not of equal density in all its parts. This is obvious from the consideration that those portions which are next the earth sustain the whole pressure of the atmosphere, while the higher strata bear only a part. The atmospheric column diminishes in length as the distance from the earth's surface increases; and, consequently, the greater the elevation the lighter must be the air. The height to which the atmosphere extends is not known with certainty, but from calculations founded on the phenomena of refraction it is supposed to be about 45 miles. If it was throughout its whole extent as dense as at the surface of the earth, its height would be about 5 miles.

402. By numerous astronomical observations, it is ascertained that the atmosphere is limited to the earth, or if not absolutely limited to the earth, that the atmospheres existing around other planets of the solar system, and especially Jupiter, are very much less than they would be, was the matter of the atmosphere distributed among the different bodies of the system in

the ratio of their several attractions. But such a distribution as this must take place, was the matter of the atmosphere infinitely divisible, and therefore capable of unlimited expansion, which is thus rendered highly improbable, if indeed it is not absolutely disproved; thus affording an unexpected argument against the infinite divisibility of matter.

403. In order to account for the fact of the atmosphere being confined to the earth, it is only necessary to suppose it to be composed of ultimate particles or atoms incapable of farther division; as, in this case, after attaining a certain degree of rarefaction, its elasticity must necessarily become so feeble that the tendency of its particles to separate farther will be counteracted by their own gravity. The unknown height at which this equilibrium takes place between the two forces of elasticity and gravitation, is the extreme limit of the atmosphere.

The loss of elasticity may be ascribed to two powerful and concurring causes; namely, to the distance between the particles of air when highly rarefied, and to the extreme cold which prevails in the higher strata of the atmosphere.

404. The best method to determine the relative quantity of oxygen in the atmosphere, is to detonate it with pure hydrogen, two measures of which will of course require precisely one measure of oxygen for its combustion. An instrument for this purpose (of which there are several varieties) is called a Eudiometer. By this instrument, though there is some difference in the results obtained by different experimenters, it is very satisfactorily determined that pure atmospheric air is composed of nitrogen about 79.34 per cent., and oxygen 20.66, by volume, or 28.3 nitrogen to 8 of oxygen, by weight.

405. It has been supposed that this ratio is ever perfectly uniform, whatever may have been the sources from which the constituent gases have been derived; but some recent experiments seem to indicate that the proportion of oxygen is greater in low latitudes, and near the surface, than near the poles or in very elevated regions, though the difference is but small.

406. Such is the constitution of pure atmospheric air. But the atmosphere is never absolutely pure; for it always contains a certain variable quantity of carbonic acid and watery vapor, besides the odoriferous matter of flowers and other volatile substances, which are also frequently present. The proportion of carbonic acid is greater in summer than in winter; and from observations made during spring, summer, and autumn, in the open fields and in calm weather, its proportion is inferred to be always greater at night than in the day, and to be more abundant in gloomy than in bright weather. A very moist state of the ground, as after much rain, diminishes the quantity of carbonic acid, apparently by direct absorption. It is rather more abundant in elevated situations, as on the summits of high mountains, than in the plains; but its quantity is there nearly the same in day and night, in wet and dry weather, because the higher strata of the air are less influenced by vegetation and the state of the soil. It has been found that 10,000 parts

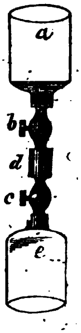
of the air contain 4.9 of carbonic acid as a mean, 6.2 as a maximum, and 3.7 as a minimum.

407. The chief chemical properties of the atmosphere are owing to the presence of oxygen gas. Air, from which this principle has been withdrawn, is nearly inert. It can no longer support respiration and combustion, and metals are not oxydized by being heated in it. Most of the spontaneous changes which mineral and dead organized matters undergo, are owing to the powerful affinities of oxygen. The uses of the nitrogen are in a great measure unknown. It has been supposed to act as a mere diluent to the oxygen; but it most probably serves some useful purpose in the economy of animals, the exact nature of which has not been discovered.

408. The question has been much discussed whether the oxygen and nitrogen gases of the atmosphere are simply intermixed, or chemically combined with each other. Appearances are at first view greatly in favor of the latter opinion.

The two gases, nitrogen and oxygen, are always found to exist in the air in the same, or nearly the same ratio, which is by volume nearly as 4 of nitrogen to 1 of oxygen, or by weight (as we have just seen), as 28.3 of nitrogen to 8 of oxygen; and to this may be added that they are always equally, or very nearly equally diffused. But, on the other hand, atmospheric air is so precisely like a simple mixture of the two gases in all its proportions, the gases suffering no change, as would be expected did they combine chemically, it is now generally believed it is merely a mixture.

Fig. 68.



409. It has been supposed that if they are merely in a state of mixture, oxygen being the most dense ought to settle towards the surface of the earth, but it is found by experiment that gases, whatever may be their relative density when brought in contact, mix uniformly with each other. Thus, if two bottles, *a* and *e*, figure 68, are each filled with a gas, the most dense being in the lower, and are then made to communicate together by means of the faucets *b* and *c*, and connecting tube *d*, the two gases will gradually diffuse themselves equally through the whole space. The mixture of the gases will even take place through their membranes, whether animal or vegetable; the least dense of the gases passing much the most rapidly.

410. There is still one circumstance for consideration respecting the atmosphere. Since oxygen is necessary to combustion, to the respiration of animals, and to various other natural operations, by all of which that gas is withdrawn from the air, it is obvious that its quantity would gradually diminish, unless the tendency of those causes were counteracted by some compensating process. To all appearance there does exist some source of compensation; for chemists have not hitherto noticed any change in the constitution of the atmosphere. The only source by which oxygen is known to be supplied, is the action of growing vegetables. A healthy plant absorbs carbonic acid during the day, appropriates the carbonaceous part of that gas to its own wants, and evolves the oxygen with which it was combined. During the night, indeed, an opposite effect is produced. Oxygen gas then disappears, and carbonic acid is eliminated; but during 24 hours they yield more oxygen than they consume. Whether living vegetables make a full compensation

for the oxygen removed from the air by the processes above mentioned is uncertain. From the great extent of the atmosphere, and the continual agitation to which its different parts are subject by the action of winds, the effects of any deteriorating process would be very gradual, and a change in the proportion of its elements could be perceived only by observations made at very distant intervals.

It has been estimated that the loss of oxygen employed in respiration and combustion, during 100 years, would not amount to $\frac{1}{7200}$ of the whole quantity in the atmosphere.

411. *Protoxide of Nitrogen.*—This gas was discovered by Priestley, who gave it the name of *dephlogisticated nitrous air*. Davy called it *nitrous oxide.* The most convenient method of procuring it is by means of nitrate of ammonia. This salt is prepared by neutralizing with carbonate of ammonia, pure nitric acid, diluted with about three parts of water, and concentrating by evaporation until a drop of the liquid let fall on a cold plate becomes a firm mass, adding a little ammonia towards the close to insure neutrality. The salt after cooling is broken to pieces, introduced into a retort, and heated by a lamp or pan of charcoal: at first, below 400°, fusion ensues; and as the heat rises to 480° or 500°, rapid decomposition sets in, which continues until all the salt disappears. If a white cloud appears within the retort, due to some of the salt subliming undecomposed, the heat should be checked.

412. The sole products of this operation, when carefully conducted, are water and protoxide of ntrogen, both the nitric acid and the ammonia being entirely decomposed. The nature of the change, which is produced simply by heating the salt, will be readily understood from the following formula: $NO_5, NH_3 = 2NO + 3HO$. Every atom of nitrate of ammonia yields two atoms of the protoxide and three atoms of water.

413. Protoxide of nitrogen is a colorless gas, with a sweetish taste and smell. Recently boiled water which has cooled without exposure to the air, absorbs nearly its own bulk of it at 60° and gives it out again unchanged by boiling. The solution, like the gas itself, has a faint, agreeable odor, and sweet taste. The action of water upon it affords a ready means of testing its purity; removing it readily from all other gases, such as oxygen and nitrogen, which are sparingly absorbed by that liquid. For the same reason it cannot be preserved over cold water; but should be collected either over hot water or mercury, or water saturated with common salt.

Protoxide of nitrogen is a supporter of combustion. Most substances burn in it with far greater energy than in the atmosphere. When a recently extinguished candle with a very red wick is introduced into it, the flame is instantly restored.— Phosphorus, if previously kindled, burns in it with great brilliancy, but may even be sublimed in it without change if it has not previously been ignited. Iron wire may also be made to burn in it for a few minutes, but not so readily as in pure oxygen. With an equal bulk of hydrogen it forms a mixture which explodes violently by the electric spark or by flame. In all these cases, the product of the combustion is the same as when oxygen gas or atmospheric air is used. The protoxide is decomposed; the combustible matter unites with its oxygen, and the nitrogen is set free.

As 100 cubic inches of this gas weigh 47.22 grains, its specific gravity must be about 1.52.

414. Davy discovered that protoxide of nitrogen may be taken into the lungs with safety, and that it supports respiration for a few minutes. Its action on the system, when inspired, is very remarkable. A few deep inspirations are followed by the most agreeable feelings of excitement, similar to the earlier stages of intoxication. This is shown by a strong propensity to laughter, by a rapid flow of vivid ideas, and an unusual disposition to muscular exertion. These feelings, however, soon subside; and the person returns to his usual state without experiencing the languor or depression which so universally follows intoxication from spirituous liquors. Its effects, however, on different persons are various; and in individuals of a plethoric habit, it sometimes produces giddiness, headache, and other disagreeable symptoms.

415. *Binoxide of Nitrogen.*—This gas was discovered by Dr. Hales. It was first carefully studied by Priestley, who called it *nitrous air.* The terms *nitrous gas* and *nitric oxide* are frequently applied to it; but *binoxide of nitrogen*, as indicative of its nature, is the most suitable appellation.

It is best obtained by the action of nitric acid a little diluted, upon metallic copper or mercury. Brisk effervescence takes place, and a part of the acid is decomposed, each atom yielding 3 atoms of oxygen to unite with the metal, and 1 atom of the binoxide, the oxide of copper thus formed being immediately taken up by another portion of the acid. From 4 atoms of nitric acid and 3 of copper, there are formed 3 atoms of nitrate of copper and 1 atom of binoxide of nitrogen, as is shown by the following formula: $4NO_5+Cu_3=3(CuO, NO_5)+NO_2$.

Fig. 69.

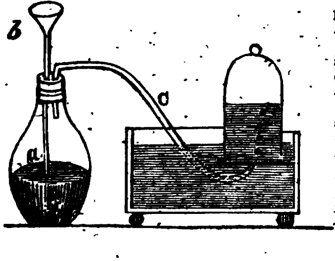


Fig. 69 represents a very convenient apparatus for preparing this as well as some other gases. Into the glass vessel *a* put some clean pieces of metallic copper, and then introduce the cover through which passes a glass tube *b*, with a funnel at top and extending nearly to the bottom of the vessel, and a lead tube *c* bent at right angles to convey away the gas as it is formed. The cover must fit very accurately, in order to prevent the escape of the gas, which is rapidly formed as soon as a little dilute nitric acid is introduced by the funnel and tube *b*. It may be collected over water.

416. Binoxide of nitrogen is a colorless gas, but its taste and odor cannot be determined. When mixed with atmospheric air; or any gaseous mixture that contains oxygen in an uncombined state, dense, suffocating, acid vapors, of a red or orange color, are produced, called *nitrous acid vapors.;* which are copiously absorbed by water, and communicate acidity to it. This character serves to distinguish the binoxide from every other substance, and affords a convenient test of the presence of free oxygen. Though it gives rise to an acid by combining with oxygen, binoxide of nitrogen itself does not redden the blue color of vegetables; but for this experiment, the gas must be previously well washed with water, to separate all traces of nitrous acid.—Water absorbs about 11 per cent. of the gas.

Very few substances are capable of burning in binoxide of nitrogen. Burning sulphur and a lighted candle are instantly extinguished by it. Charcoal and phosphorus, however, if in a state of vivid combustion at the moment of being immersed in it, burn with increased brilliancy. The product of the combustion is carbonic acid in the former case, and phosphoric acid in the latter, nitrogen being separated in both instances.

Binoxide of nitrogen is quite irrespirable, exciting strong spasm of the glottis, as soon as an attempt is made to inhale it. The experiment, however, is a dangerous one; for if the gas did reach the lungs, it would there mix with atmospheric air, and be converted into nitrous acid vapors, which are highly irritating and corrosive.

417. From the invariable formation of red-colored acid vapors, whenever binoxide of nitrogen and oxygen are mixed together, these gases detect the presence of each other with great certainty; and since the product is wholly absorbed by water, either of them may be entirely removed from any gaseous mixture by adding a sufficient quantity of the other.

The specific gravity of this gas is 1.04, 100 cubic inches weighing 32.14.

418. A beautiful experiment illustrating the action of binoxide of nitrogen with oxygen, is to pass up a current of oxygen slowly into a receiver filled with it over water slightly colored with solution of litmus. The oxygen combines with the binoxide, forming nitrous acid, which appears in dense orange-colored fumes, but which rapidly disappears again, the rise of the water in the receiver showing the absorption which is taking place, and the change in the color of the litmus solution indicating the formation of nitrous acid

419. *Hyponitrous Acid.*—This acid is formed by adding 400 measures of binoxide of nitrogen to 100 measures of oxygen, both gases quite dry

and exposing the orange-colored fumes thus formed to a cold of 0°, by which it is condensed into a liquid.

Hyponitrous acid does not unite directly with alkalies, being then resolved principally into nitric acid and binoxide of nitrogen; but the hyponitrites of the alkalies and alkaline earths may be obtained by heating the corresponding nitrates to a gentle red heat; and the hyponitrite of the oxide of lead is formed by boiling a solution of the nitrate of that oxide with metallic lead.

420. Hyponitrous acid forms with water and sulphuric acid a crystaline compound, which is generated in large quantity during the manufacture of sulphuric acid, and the production of which is an essential part of that process. It is formed whenever moist sulphurous acid gas and nitrous acid vapor are intermixed, being instantly deposited in the form of white acicular crystals; it may also be made by the direct action of anhydrous nitrous and strong sulphuric acid.

421. *Nitrous Acid.*—This acid is formed by mixing together binoxide of nitrogen and oxygen; but the best method of preparing it is to heat the dry nitrate of lead to redness in an earthen retort, which results in the production of oxide of lead, oxygen, and nitrous acid. Thus, $PbO, NO^5 = PbO + O + NO^4$. On receiving the oxygen and nitrous acid in a dry glass vessel surrounded by snow and salt, the acid is condensed to a liquid, while the oxygen, as a matter of course, escapes.

The liquid as thus obtained is anhydrous; is acid and pungent to the taste, gives a yellow stain to the skin, and is powerfully corrosive. At common temperatures its color is an orange-red; but it becomes yellow when cooled below 32°, and at 0° is nearly colorless. Its density is 1.45. It is extremely volatile, boiling at 82°: in a stoppered bottle it preserves its liquid form at common temperatures; but when exposed to the atmosphere it is rapidly dissipated, forming nitrous acid vapors which, when once mixed with air or other gases, require intense cold for condensation.

In the form of vapor this acid is characterized by its orange-red color, acid reaction to test paper, and by being absorbed by water with disengagement of binoxide of nitrogen and formation of nitric acid. It is quite irrespirable, exciting great irritation and spasm of the glottis, even when moderately diluted with air. A taper burns in it with considerable brilliancy. It extinguishes burning sulphur; but the combustion of phosphorus continues in it with great vividness.

422. Nitrous acid is a powerful oxydizing agent, readily giving oxygen to the more oxydable metals, and to most substances which have a strong affinity for it.

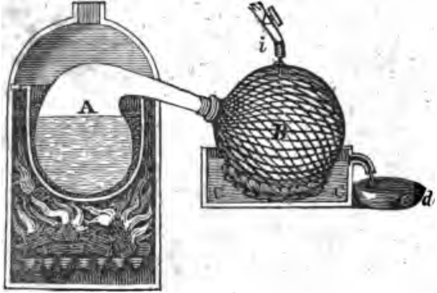
Nitrous acid when pure is instantly decomposed by contact with water, being converted into nitric acid and binoxide of nitrogen, according to the following formula: $3NO^4 = 2NO^5 + NO^2$.

Nitric Acid.—This acid may be formed by passing a succession of powerful electric sparks through a mixture of oxygen and nitrogen confined in a glass tube over mercury, a little water being present.

Nitric acid cannot exist in an insulated state. Binoxide of nitrogen and oxygen gases never form nitric acid if mixed together when quite dry; and nitrous acid vapor may be kept in contact with oxygen gas without change, provided no water is present. The most simple form under which chemists have hitherto procured nitric acid is in solution with water; a liquid which, in its concentrated state, is the nitric acid of the Pharmacopœia. By manufacturers it is better known by the name of *aqua fortis*.

423. The nitric acid of commerce is produced by decomposing some salt of nitric acid by means of oil of vitriol; and common nitre, as the cheapest of the nitrates, is employed for the purpose. This salt, previously well dried, is put into a glass retort, and an equal weight of the strongest oil of vitriol is poured upon it. On applying heat, ebullition ensues, owing to the escape of nitric acid vapors, which must be collected in a cool receiver. The heat should be steadily increased during the operation, and continued as long as any acid vapors come over.

Fig. 70.



424. The apparatus represented in figure 70, answers well for preparing this acid. A glass retort A, containing the nitrate of potassa and an equal weight of sulphuric acid, is placed in a sand bath in a furnace. As the nitric acid is separated it distils over into the receiver B, where it is condensed. To render the condensation more complete, the receiver is surrounded with a net-work, and water from a pipe *i* falls constantly upon it, and escapes by the troughs CC and *de*.

425. The acid thus formed is always more or less colored by the nitrous acid, which is produced by the decomposition of a small portion of the nitric as it quits the potassa; for at the commencement and close of the operation, nitrous acid fumes are disengaged, which communicate a straw-yellow or an orange-red tint, according to their quantity. If a very pale acid is required, two receivers should be used; one for condensing the colorless vapors of nitric acid, and another for the colored products. The colored acid is often called nitrous acid; but it is in reality a mixture or compound of nitric and nitrous acids, similar to what may be obtained by mixing anhydrous nitrous with colorless nitric acid. It is easy to convert the common mixed acid into colorless nitric acid, by exposing the former to a gentle heat for some time, when all the nitrous acid will be expelled. But this process is rarely necessary, as the colored acid may be substituted in most cases for that which is colorless. Where an acid of great strength is required, the former is even preferable.

Nitrate of soda being more abundant and cheaper than nitrate of potassa, is now generally used in the large manufactories of nitric acid.

Nitric acid frequently contains portions of sulphuric and hydrochloric acid. The former is derived from the acid which is used in the process; and the latter from sea-salt, which is frequently mixed with nitre. These impurities may easily be detected and removed.

426. Nitric acid possesses acid properties in an eminent degree Its specific gravity when most concentrated, according to Kane s 1.52, and it is then a compound of 1 eq. of nitric acid and 1 eq. of water; that is, it contains 14.29 per cent. of water. Its boiling point is 187, but it cannot be distilled without decomposition. Combined with water in the ratio of 1 eq. of acid to 4 eq. of water, its sp. gr. is 1.42, and it boils at 248°. It may then be distilled without change. An acid of lower density than 1.42 becomes stronger by being heated, because the water evaporates more rapidly than the acid. An acid, on the contrary, which is stronger than 1.42, is weakened by the application of heat.

Strong nitric acid, when exposed to the atmosphere, emits dense, white fumes, which are exceedingly suffocating. Mixed suddenly with water, it occasions a considerable rise of temperature; but mixed with snow, it produces cold by the rapid liquefaction which is occasioned.

There are two varieties of nitric acid, known in commerce as *single* and *double aqua fortis*, both of which are much diluted with water; the strongest of the double aqua fortis, it is believed, seldom possesses a specific gravity as high as 1.40.

Nitric acid may be frozen by cold. The temperature at which congelation takes place varies with the strength of the acid. The strongest acid freezes at about 50° below zero. When diluted with half its weight of water, it becomes solid at —1½°. By the addition of a little more water, its freezing point is lowered to —45°.

Nitric acid acts powerfully on substances which are disposed to unite with oxygen; and hence it is much employed by chemists for bringing bodies to their maximum of oxydation. Nearly all the metals are oxydized by it; and some of them, such as tin, copper, and mercury, are attacked with great violence. If flung on burning charcoal, it increases the brilliancy of its combustion in a high degree. Sulphur and phosphorus are converted into acids by its action, and dry warm charcoal in fine powder may be ignited by it, and oil of turpentine inflamed. But it is very seldom that nitric acid of sufficient strength for this purpose can be procured in commerce, but the experimenter will be under the necessity of preparing it for himself, in which he will find no difficulty.

427. There are some singular anomalies in the action of nitric acid on the metals, the causes of which are not fully understood. When its specific gravity is 1.48, it may be brought

in contact with tin or iron, without acting upon them in the least, but if made a little stronger or weaker the action is violent; and the inactive acid may be rendered active by various means, as by simply touching the immersed metal with a different one.

428. Nitric acid decomposes all vegetable substances. In general the oxygen of the nitric acid enters into direct combination with the hydrogen and carbon of those compounds, forming water with the former, and carbonic acid with the latter. This happens remarkably in those compounds in which hydrogen and carbon are predominant, as in alcohol and the oils. It effects the decomposition of animal matters also. The cuticle and nails receive a permanent yellow stain when touched with it; and if applied to the skin in sufficient quantity, it acts as a powerful cautery, destroying the organization of the part entirely.

429. Gold-leaf answers well in most cases as a test for nitric acid. The substance supposed to contain it is mixed with a little hydrochloric acid, and the mixture, if nitric acid is really present, should then be capable of dissolving the leaf. If it is a salt that is to be tested, it should first be dissolved in water and the solution treated in the same manner with hydrochloric acid and gold-leaf.

430. A very delicate test has been proposed, founded on the orange-red followed by a yellow color, which nitric acid communicates to morphia. The supposed nitrate is heated in a test-tube with a drop of sulphuric acid, and then a crystal of morphia is added. It is advisable to try the process in a separate tube with the sulphuric acid alone, in order to prove the absence of nitric acid.

431. Nitric acid is much used in the arts for etching on copper, as a solvent for the metals, &c., and as a tonic in medicine. In the laboratory of the chemist, it is in constant and most important use in a great variety of operations.

NITROGEN AND HYDROGEN.

432. Ammonia is is the only compound of nitrogen and hydrogen which has been obtained in a separate state; but two others are believed to exist in combination, the composition of which will be seen in the following table:

	Nitr.	*Hydr.*	*Equiv.*	*Symbols.*
Hyduret of nitrogen or amide,	1 eq.+	2 eq.—	16.15=	NH_2 or Ad
Hyduret of amide or ammonia,	1 eq.+	3 eq.—	17.15=	NH_3 " AdH
Ammonium..........................	1 eq.+	4 eq.—	18.15=	NH_4 " AdH_2

433. *Ammonia.*—This substance has been long known under the names of *hartshorn, spirits of hartshorn, volatile alkali, spirit of sal ammoniac,* &c. It exists in a state of purity only in the gaseous form, as was first shown by Priestley.

The most convenient method of preparing ammoniacal gas for the purposes of experiment, is by applying a gentle heat to the concentrated solution of ammonia, contained in a glass vessel. It soon enters into ebullition, and a large quantity of pure ammonia is disengaged.

Ammonia is also produced in nearly all reactions in which nitrogen and hydrogen are brought together, one or both being in the nascent state. When the electric spark passes through damp air, both ammonia and nitric acid are produced, and hence nitrate of ammonia may often be detected in rain that falls during a thunder-storm.

An abundant supply of ammoniacal gas may be obtained by heating a mixture of equal parts of hydrochlorate of ammonia and dry quicklime recently slaked.

434. Ammonia is a colorless gas, which has a strong pungent odor, and acts powerfully on the eyes and nose. It is quite irrespirable in its pure form, but when diluted with air, it may be taken into the lungs with safety. Burning bodies are extinguished by it, nor is the gas inflamed by their approach. Ammonia, however, is inflammable in a low degree; for when a lighted candle is immersed in it, the flame is somewhat enlarged, and tinged of a pale yellow color at the moment of being extinguished; and a small jet of the gas will burn in an atmosphere of oxygen. A mixture of ammoniacal and oxygen gases detonates by the electric spark; water being formed, and nitrogen set free. A little nitric acid is generated at the same time, except when a smaller quantity of oxygen is employed than is sufficient for combining with all the hydrogen of the ammonia.

Ammoniacal gas at the temperature of 50° and under a pressure equal to 6.5 atmospheres, becomes a transparent, colorless liquid. It may also be liquefied under the ordinary pressure of the atmosphere, by causing a current of it to pass into a small receiver kept at a very low temperature by the evaporation of liquid sulphurous acid.

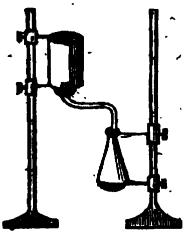
435. Ammonia has all the properties of an alkali in a very marked manner. Thus it has an acrid taste, and gives a brown stain to turmeric paper; though the yellow color soon reappears on exposure to the air, owing to the volatility of the alkali. It combines also with acids, and neutralizes their properties completely. But in these cases it is now believed it is generally, if not always, the oxide of ammonium (432) that unites with the acid, and not the ammonia directly, as will be seen hereafter.

436. Hydrogen and nitrogen gases do not unite directly, and therefore chemists have no synthetic proof of the constitution of ammonia. Its composition, however, has been determined analytically with great exactness. When a succession of electric sparks is passed through ammoniacal gas, it is resolved into its elements; and the same effect is produced by con-

ducting ammonia through porcelain tubes heated to redness. Ammonia is composed of 100 vols. of nitrogen united with 300 vols. of hydrogen, and the whole condensed to 200 vols. The specific gravity of the gas is therefore 0.59, and 100 cubic inches weigh 18.29 grs.

In consequence of its great affinity for water, the gas must always be collected over mercury. If allowed to pass into water it is rapidly absorbed by it, and the solution formed which is commonly, though very incorrectly, called *liquid ammonia*. During the absorption the volume of the water is increased and the temperature much raised, unless surrounded with ice. Water at 32° may in this manner be made to absorb 780 times its own volume, and the clear colorless solution has a specific gravity of 0.87. It possesses the peculiar pungent odor, taste, alkalinity, and other properties of the gas itself. On account of its great volatility, it should be preserved in well-stopped bottles, a measure which is also required to prevent the absorption of carbonic acid. At a temperature of 130° it enters into ebullition, owing to the rapid escape of pure ammonia; but the whole of the gas cannot be expelled by this means, as at last the solution itself evaporates. It freezes at about the same temperature as mercury, which is —39°.

Fig. 71.



If a little of the gas is desired, in consequence of its being lighter than atmospheric air, it may be collected quite pure in an inverted jar filled merely with air, as represented in figure 71. As soon as it is filled, it must be corked tightly and removed. Its presence may always be detected by its pungent odor, and by the dense white fumes it gives with hydrochloric acid gas.

437. Ammonia is used extensively in the laboratory of the chemist, and in medicine. Solution of ammonia taken internally in considerable quantity has been known to produce death; and the gas, if inspired too long, is apt to produce inflammation in the throat and lungs.

SECTION IV.

CARBON.

Symbol C; Equivalent 6.12.

438. Carbon, though rarely met with pure and uncombined, is one of the most important elements in nature; its various compounds are more generally and abundantly distributed than

those of any other substance, and it may be said to form the basis of the whole organic creation.

439. It occurs in its purest form in the diamond, a mineral of unknown origin, found usually in primitive soils. It is the essential principle of every variety of *charcoal*—the black mass left formed where most vegetable and animal substances are heated to redness in close vessels. Common charcoal contains about $\frac{1}{50}$th of its weight of alkaline and earthy salts, which constitutes the ashes after its combustion. *Coke* is the charcoal from bituminous coal; *ivory black* or *animal charcoal* is that from ivory or bones, and *lamp-black* from rosin. Very pure charcoal may be prepared from alcohol, turpentine, gum, sugar, starch, &c.

440. Carbon, as it exists crystalized in the diamond, is the hardest substance known in nature. Its primary form is the regular octohedron. Its specific gravity is 3.52. It resists the action of both acids and alkalies; and bears the most intense heat in close vessels without fusing or undergoing any perceptible change. Heated to redness in the open air, it is entirely consumed.

Newton first suspected it to be combustible, from its great refractive power; and the fact was afterwards proved by Lavoisier, by throwing upon it, in a receiver of oxygen gas, the focus of a powerful lens. The diamond was entirely consumed, oxygen disappeared, and carbonic acid was generated, just as would have been the case had the same weight of charcoal been consumed instead of the diamond. The same experiment has since often been repeated with the same results.

441. Charcoal, as obtained from wood, is hard and brittle, conducts heat very slowly, but as usually prepared, at a high temperature, is a very good conductor of electricity. If it is prepared by heating in close vessels, at a temperature not exceeding the boiling point of mercury, till vapors cease to rise, it is said to possess properties in many respects quite different, being then a non-conductor of electricity, and producing flame during combustion.

442. Prepared in either manner it is quite insoluble in water, is attacked with difficulty by nitric acid, and is little affected by any of the other acids, or by the alkalies. It undergoes little change from exposure to air and moisture, being less injured under these circumstances than wood. It is exceedingly refractory in the fire, if excluded from the air, supporting the most intense heat without change.

443. Charcoal possesses the property of absorbing a large quantity of air or other gases at common temperatures, and of yielding the greater part of them again when it is heated. Different gases are absorbed by it in different proportions; thus while charcoal from boxwood absorbs in the space of forty-eight

hours 90 times its own volume of ammoniacal gas, 85 of hydrochloric, and 35 of carbonic acid, and olefiant gas, it will in the same time take up only 7.5 times its volume of nitrogen and 1.75 of hydrogen.

444. The cause of this absorbing power of charcoal is not understood; it varies greatly in different varieties of charcoal, and in plumbago and anthracite is entirely wanting.

445. Recently burned charcoal absorbs air and moisture so rapidly for a few days as materially to increase its weight. In one instance, charcoal from fir was found to have gained in one week's exposure, 13 per cent.; that from *lignum vitæ*, 9.6; that from box, 14; from beech, 16.3; from oak, 16.5; and from mahogany, 18. The absorption is most rapid during the first twenty-four hours. The substance absorbed is both water and atmospheric air, which the charcoal retains with such force, that it cannot be completely separated from them without exposure to a red heat.

446. Charcoal likewise absorbs the odoriferous and coloring principles of most animal and vegetable substances. When colored infusions of this kind are digested with a due quantity of charcoal, a solution is obtained, which is nearly if not quite colorless. Tainted flesh may be deprived of its odor by this means, and foul water be purified by filtration through charcoal. The substance commonly employed to decolorize fluids is animal charcoal reduced to a fine powder. It loses the property of absorbing coloring matters by use, but recovers it by being heated to redness.

447. Charcoal is highly combustible. When strongly heated in the open air, it takes fire and burns slowly. In oxygen gas, its combustion is lively, and accompanied with the emission of sparks. In both cases it is consumed without flame and smoke; and carbonic acid gas is the product of its combustion.

If some one or two tons of charcoal in fine powder are placed in a single heap, it is said it will almost certainly take fire spontaneously, but the cause has not been explained.

448. Graphite or plumbago, called also, very improperly, black lead, is carbon in a mineralized state, containing usually about 5 per cent. of iron. Some doubt has been entertained whether it should be considered a chemical compound of these substances or not, but the probability is it is a peculiar form of carbon, the iron and other impurities contained in it being merely accidental. It is often found crystalized in thin scales.

Carbon is used as fuel; in forming gunpowder; as a pigment; in the formation of steel; as a polishing powder; and in medicine as an antiseptic, &c. &c.

CARBON AND OXYGEN.

The only compounds of carbon and oxygen known are the two following, viz:

	Carbon.	Oxygen.	Equiv.	Symbols
Carbonic oxide	1 eq. +	1 eq.	14.12	CO
Carbonic acid	1 eq. +	2 eq.	22.12	CO_2

449. *Carbonic Oxide or Protoxide of Carbon.*—This substance in a state of purity has been obtained only in the gaseous form. There are various methods of preparing it, but one only will be described. When equal parts of well-dried chalk in fine powder and iron filings are thoroughly mixed, and exposed to a red heat in a gun-barrel, a large quantity of gaseous matter passes over, which, after washing it well with limewater or solution of potassa to separate it from carbonic acid, a compound to be next described, is found to be very pure carbonic oxide. The chalk, which is a carbonate of lime, when heated to redness gives off its carbonic acid, but the red-hot iron being present, instantly absorbs one equivalent of its oxygen, and thus forms carbonic oxide. The changes are illustrated by symbols, as follows: $Fe+CaO, CO_2=FeO+CaO+CO$.

Carbonic oxide gas is colorless and insipid. It is neither acid nor alkaline; is sparingly absorbed by water, but does not render lime-water turbid like carbonic acid.

Carbonic oxide is inflammable. When a lighted taper is plunged into a jar full of that gas, the taper is extinguished; but the gas itself is set on fire, and burns calmly at its surface with a lambent blue flame.

The blue flame which is seen playing over ignited charcoal is caused by the combustion of this gas.

Carbonic oxide gas cannot support respiration. It acts injuriously on the system; for if diluted with air, and taken into the lungs, it very soon occasions headache and other unpleasant feelings; and when breathed pure, it almost instantly causes profound coma.

450. A mixture of carbonic oxide and oxygen gases may be made to explode by flame, by a red-hot solid body, or by the electric spark.

Carbonic oxide is composed of one equivalent of carbon united with one equivalent of oxygen. Its specific gravity is 0.97. Hence 100 cubic inches should weigh 30.08 grs.

451. *Carbonic Acid.*—This substance was discovered by Black, in 1757, and described by him in his inaugural dissertation on magnesia, under the name of *fixed air.* He observed the existence of this gas in common limestone and magnesia, and found that it may be expelled from these substances by the action of heat or acids. He also remarked that the same gas is formed during respiration, fermentation, and combustion. Its composition was first demonstrated synthetically by Lavoisier, who burned carbon in oxygen gas, and obtained carbonic acid as the product.

Carbonic acid is most conveniently prepared for the purposes of experiment by the action of hydrochloric acid, diluted with two or three times its weight of water, on fragments of marble, when the hydrochloric acid takes the lime, and carbonic acid gas escapes with effervescence.

Carbonic acid, as thus procured, is a colorless, inodorous, elastic fluid, which possesses all the physical characters of the gases in an eminent degree, and requires a pressure of thirty-six atmospheres at 32° to condense it into a liquid. Its specific gravity 1.52, and 100 cubic inches, therefore, weigh 47.14 grs. The sp. gr. of the liquid at 32° is 0.83, water being 1, but it dilates remarkably by heat, its expansion being more than 4 times as great as that of the gases. Heated from 32° to 86°, its elasticity increases from 36 atmospheres to 73, being about 0.68 of an atmosphere for each degree. A jet of the liquid being allowed to escape in the air evaporates with great rapidity and produces such intense cold that a part of it is frozen (120).

452. Carbonic acid extinguishes burning substances of all kinds, and the combustion does not cease from the want of oxygen only. It exerts a positive influence in checking combustion, as appears from the fact that a candle cannot burn in a gaseous mixture composed of four measures of atmospheric air and one of carbonic acid.

453. It is not better qualified to support the respiration of animals; for its presence, even in moderate proportion, is soon fatal. An animal cannot live in air which contains sufficient carbonic acid for extinguishing a lighted candle; and hence the practical rule of letting down a burning taper into old wells or pits before any one ventures to descend. If the light is extinguished, the air is certainly impure; and there is generally thought to be no danger, if the candle continues to burn. But some instances have been known of the atmosphere being sufficiently loaded with carbonic acid to produce insensibility, and yet not so impure as to extinguish a burning candle. When an attempt is made to inspire pure carbonic acid, violent spasm of the glottis takes place, which prevents the gas from entering the lungs. If it be so much diluted with air as to admit of its passing the glottis, it then acts as a narcotic poison on the system. It is this gas which has so often proved destructive to persons sleeping in a confined room with a pan of burning charcoal.

454. It is quite incombustible, and cannot be made to unite with an additional portion of oxygen. It is a compound, therefore, in which carbon is in its highest degree of oxydation.

Lime-water becomes turbid when brought into contact with carbonic acid. The lime unites with the gas, forming carbonate of lime, which, from its insolubility in water, at first renders the solution milky, and afterwards forms a white flaky precipitate. Hence lime-water is not only a valuable test of the presence of carbonic acid, but is frequently used to withdraw it altogether from any gaseous mixture that contains it.

Recently boiled water dissolves its own volume of carbonic acid at the common temperature and pressure; but it will take up much more if the pressure be increased. The quantity of the gas absorbed is in exact ratio with the compressing force; that is, water dissolves twice its volume when the pressure is doubled, and three times its volume when the pressure is trebled.

455. Soda fountains, as they are called, consist simply of water under strong pressure thus impregnated with carbonic acid, a large portion of which of course escapes as soon as the water comes into the open air, producing the violent effervescence which is witnessed. Soda powders, often used to produce an agreeable drink in the absence of a soda fountain, consist of bicarbonate of soda and tartaric acid, which, when mingled together in solution, produce by chemical action tartrate of soda, the carbonic acid passing off into the air, with effervescence.

The effervescence which takes place on opening a bottle of ginger-beer, cider, or brisk champaigne, is owing to the escape of carbonic acid gas. Water, which is fully saturated with carbonic acid gas, sparkles when it is poured from one vessel into another. The solution has an agreeably acidulous taste, and gives to litmus paper a red stain, which is lost on exposure to the air. On the addition of lime-water to it, a cloudiness is produced, which at first disappears, because the carbonate of lime is soluble in excess of carbonic acid; but a permanent precipitate ensues when the free acid is neutralized by an additional quantity of lime-water. The water which contains carbonic acid in solution is wholly deprived of the gas by boiling. Removal of pressure from its surface by means of the air-pump has a similar effect.

The agreeable pungency of beer, porter, and ale, is in a great measure owing to the presence of carbonic acid; by the loss of which, on exposure to the air, they become stale. All kinds of spring and well water contain carbonic acid absorbed from the atmosphere, and to which they are partly indebted for their pleasant flavor. Boiled water has an insipid taste, from the absence of carbonic acid.

456. Carbonic acid is always present in the atmosphere, even at the summit of the highest mountains, or at a distance of several thousand feet above the ground. Its presence may be demonstrated by exposing lime-water in an open vessel to the air, when its surface will soon be covered with a pellicle, which is carbonate of lime. But though constantly supplied by various natural operations, the quantity is not increased.

457. This gas sometimes collects in large quantities in mines, and is called *choke-damp*. It is probably in most cases produced

by decaying vegetable matter. Sometimes it collects in this manner in wells.

458. For this reason a person should never descend into a well or enter a cavern without first taking measures to ascertain the state of the atmosphere contained in it. To determine this in a well, a lighted candle may be let down by means of a rope, which will be extinguished if there is enough carbonic acid present to cause any danger (453). If the candle is extinguished, the air must be purified before it can be entered, by letting down a quantity of recently slaked lime, by which the carbonic acid is rapidly absorbed, or it may be ventilated by means of ignited charcoal, let down in an iron basin. The heat of the burning charcoal produces ascending currents in the impure air, by which it will at length be removed and its place supplied by fresh air from the open atmosphere.

CARBON AND HYDROGEN.

459. Chemists have for several years been acquainted with two distinct compounds of carbon and hydrogen, viz., carburetted hydrogen and olefiant gas; but late researches have enriched the science with several other compounds of a similar nature, to which much interest is attached. They are remarkable for their number; for supplying some instructive instances of isomerism (342); and for their tendency to unite with and even neutralize powerful acids, though in an uncombined state they manifest no signs of alkalinity. Several of them exhibit in their combinations with other substances many of the characteristics of elements, and have hence been called compound radicals. These will be described in organic chemistry, where they properly belong, so far as they come within the object of the work. At present the two following only, will be introduced.

	Hydrogen.	*Carbon.*	*Equiv.*	*Symbol.*
Light carburetted hydrogen	2 eq. +	1 eq. —	8.12	H_2C
Olefiant gas	4 eq. +	4 eq. —	28.48	H_4C_4

460. *Light Carburetted Hydrogen.*—This gas is sometimes called *heavy inflammable air*, the *inflammable air of marshes*, and *hydrocarburet*. Agreeably to the principles of the chemical nomenclature, taking carbon as the electro-negative element, it is a *dicarburet of hydrogen*; but it is generally termed *light carburetted hydrogen*. It is formed abundantly in stagnant pools during the spontaneous decomposition of dead vegetable matter; and it may readily be procured by stirring the mud at the bottom of them, and collecting the gas as it escapes in an inverted glass vessel. In this state it is found to contain $\frac{1}{20}$th of carbonic acid gas, which may be removed by means of lime-water or a solution of pure potassa, and $\frac{1}{15}$th or $\frac{1}{20}$th of nitrogen. This is the only convenient method of obtaining it.

461. Light carburetted hydrogen is tasteless and nearly inodorous, and it does not change the color of litmus or turmeric paper. Water absorbs about $\frac{1}{60}$th of its volume. It extinguishes

all burning bodies, and is unable to support the respiration of animals. It is highly inflammable; and when a jet of it is set on fire, it burns with a yellow flame, and with a much stronger light than is occasioned by hydrogen gas. With a due proportion of atmospheric air or oxygen gas, it forms a mixture which detonates powerfully with the electric spark, or by the contact of flame. The sole products of the explosion are water and carbonic acid.

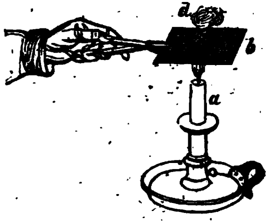
The specific gravity of this gas is 0.56, and of course 100 cubic inches weigh 17.37 grains.

462. Light carburetted hydrogen is not decomposed by electricity, nor by being passed through red-hot tubes, unless the temperature is very intense, in which case some of the gas does suffer decomposition, each volume yielding two volumes of pure hydrogen gas and a deposite of charcoal.

463. This gas is the *fire-damp* of coal mines, into which it often issues in large quantities from between the beds of coal; and by collecting there in consequence of deficient ventilation, and gradually mixing with atmospheric air, forms an explosive mixture. The first unprotected light which then approaches sets fire to the whole mass, and an explosion ensues. These accidents, which were formerly so frequent and so fatal, are now comparatively rare, owing to the employment of the safety lamp.

For this lamp we are indebted to Davy, who, in his experiments that led to its invention, discovered that this gas when mingled with atmospheric air forms an explosive mixture, provided it constitutes not less than $\frac{1}{14}$th, nor more than $\frac{1}{6}$th of the whole volume, but that the flame is not communicated through small tubes, or fine wire gauze.

Fig. 72.

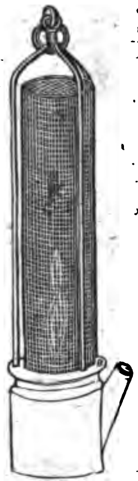


This effect of wire gauze in arresting flame may be familiarly shown by holding a piece of it *b* over the flame of a candle *a*, in the manner represented in figure 72. The combustible gases, it will be seen, pass unconsumed through the gauze, and may be kindled on the upper side *d*.

If a piece of camphor is placed on the metallic gauze and held over the lamp, it will melt and vaporize; but as it melts, a part will filter through the gauze and take fire, producing a sheet of flame in contact with the lower surface; but above, the vapor of camphor will be perfectly protected, though it continues all the while to mix with the air.

464. These principles being established, it is plain, if a common oil lamp be completely surrounded with a cage of such gauze, it may be introduced into an explosive atmosphere of fire-damp and air, without kindling the mixture. This simple

Fig. 73.



contrivance, which is appropriately termed the *safety-lamp*, not only prevents explosion, but indicates the precise moment of danger. When the lamp is carried into an atmosphere charged with fire-damp, the flame begins to enlarge; and the mixture, if highly explosive, takes fire as soon as it has passed through the gauze, and burns on its inner surface, while the light in the centre of the lamp is extinguished. Whenever this appearance is observed, the miner must instantly withdraw; for though the flame should not be able to communicate with the explosive mixture on the outside of the lamp, as long as the texture of the gauze remains entire, yet the heat emitted during the combustion is so great, that the wire, if exposed to it for a few minutes, would suffer oxydation, and fall to pieces.

The accompanying figure of the safety-lamp needs no additional explanation.

465. The operation of the lamp may be shown quite well, by pouring a little sulphuric ether into a common glass receiver, which should be inverted and agitated a little, so that it may be filled with a mixture of air and vapor of ether, and then letting the lighted lamp down into it. The mixture of air and vapor of ether entering through the gauze, burns brilliantly within the gauze, but the flame is not communicated to that without.

466. The peculiar operation of small tubes or wire gauze, in obstructing the passage of flame, has been attributed to the cooling of the heated gas by the conducting power of the metal. Flame is gaseous matter heated so intensely as to be luminous, and the temperature necessary for producing this effect is very high, even above the white heat of solid bodies, which, therefore, even in this state, produce upon it a cooling effect. Consequently, when flame comes in contact with fine wire gauze, its temperature is so reduced that combustion ceases and the gases pass on unchanged.

This explanation has been questioned, though it is believed no better one has been proposed in its place.

467. These principles suggest the conditions under which Davy's lamp would cease to be safe. If a lamp with its gauze red-hot be exposed to a *current* of explosive mixture, the flame may possibly pass so rapidly as not to be cooled below the point of ignition, and in that case an accident might occur with a lamp which would be quite safe in a calm atmosphere. It has been lately shown that flame in this way may be made to pass through the gauze of the safety-lamp, as commonly constructed. This may account for accidents in coal-mines where the safety-lamp is constantly employed. An obvious mode of avoiding such an evil is to diminish the apertures of the gauze; but this remedy is nearly impracticable, from the obstacle which very fine gauze causes to the diffusion of light. A better method is to surround the common safety-lamp with a glass cylinder, allowing air to enter solely at the bottom of the lamp, through wire gauze of extreme fineness, placed horizontally, and to escape at the top by a similar contrivance.

468. *Olefiant Gas or Hydruret of Carbon.*—This gas has also been called *bicarburetted or percarburetted hydrogen.* It was discovered in 1796, by some associated Dutch chemists, who gave it the name of *olefiant gas,* from its property of forming an oil-like liquid with chlorine.

Olefiant gas is prepared by mixing in a capacious retort one part of alcohol with four of concentrated sulphuric acid, and heating the mixture, as soon as it is made, by means of a lamp or ignited charcoal. The acid soon acts upon the alcohol, effervescence ensues, and olefiant gas passes over, mixed with other substances, chiefly sulphurous acid, from which it may be purified by washing it with solution of lime or caustic potassa.

469. Olefiant gas is a colorless elastic fluid, which when pure has no taste and scarcely any odor. Water absorbs about one-eighth of its volume. Like the preceding compound it extinguishes flame, is unable to support the respiration of animals, and is set on fire when a lighted candle is presented to it, burning slowly, with the emission of a dense white light. With a proper quantity of oxygen gas, it forms a mixture which may be kindled by flame or the electric spark, and which explodes with great violence. To burn it completely, it should be detonated with four or five times its volume of oxygen.

It is composed of 4 equivalents of carbon combined with 4 eq. of hydrogen, but 1 eq. of the hydrogen is in a different state of combination from the rest. Its sp. gr. is 0.98, and 100 cubic inches weigh 30.41 grs.

Chlorine acts powerfully on olefiant gas; and when the gases are mixed together in the ratio of two measures of the former to one of the latter, they form a mixture which takes fire on the approach of flame, and which burns rapidly with formation of hydrochloric acid gas, and deposition of a large quantity of charcoal. But if the gases are allowed to remain at rest after being mixed together, the chlorine, instead of decomposing the olefiant gas, enters into direct combination with it, and a yellow liquid like oil is generated, which will be described hereafter.

Olefiant gas, when a succession of electric sparks is passed through it, is resolved into charcoal and hydrogen; and the latter of course occupies twice as much space as the gas from which it was derived. It is also decomposed by transmission through red-hot tubes of porcelain.

CARBON AND NITROGEN.

470. There are two compounds of these substances, cyanogen, and mellon, besides paracyanogen, which is isomeric with cyanogen.

	Carbon.	*Nitrogen.*	*Equiv.*	*Symbols.*
Cyanogen	2 eq. +	1 eq. —	26.39 —	C_2N or Cy
Mellon	6 eq. +	4 eq. —	93.32 —	C_6N_4 or Ml
Paracyanogen	8 eq. +	4 eq. —	105.56 —	C_8N_4

*Bicarburet of Nitrogen or Cyanogen.**—This gas, the discovery of which was made in 1815, by Gay-Lussac, is prepared by heating carefully dried bicyanuret of mercury in a small glass retort, by means of a spirit-lamp. The cyanuret, which was formerly considered a compound of oxide of mercury and prussic acid, and was then called *prussiate of mercury*, is composed of metallic mercury and cyanogen. On exposure to a low red heat, it is resolved into its elements; the cyanogen passes over in the form of gas, and the metallic mercury is sublimed. The retort, at the close of the process, contains a small residue of a dark brown matter like charcoal, which consists of the same ingredients as the gas itself.

471. Cyanogen gas is colorless, and has a strong pungent and very peculiar odor. At the temperature of 45° and under a pressure of 3,6 atmospheres, it is a limpid liquid, which is a non-conductor of electricity, and resumes the gaseous form when the pressure is removed. It extinguishes burning bodies; but it is inflammable, and burns with a beautiful and characteristic purple flame. It can support a strong heat without decomposition. Water, at the temperature of 60°, absorbs 4.5 times and alcohol 23 times its volume of the gas.

The specific gravity of cyanogen gas is 1.82, and 100 cubic inches weigh 56.47 grs.

472. Cyanogen, though a compound body, has a remarkable tendency to combine with elementary substances. Thus it is capable of uniting with the simple non-metallic bodies, and evinces a strong attraction for metals, but manifests little disposition to combine with the oxides or other compound bodies. It is therefore analogous, in its chemical relations, to the elementary substances, and is to be considered as a "compound radical" of Organic Chemistry, where its various combinations will be described.

473. *Paracyanogen.*—After preparing cyanogen by the process above described, a brown mass is left in the retort, which is found to be a solid compound of carbon and nitrogen, a bicarburet of nitrogen, isomeric with cyanogen; and it has been suggested that the carbonaceous residue, after the charring of animal substances, is probably in many cases a carburet of nitrogen, and not pure charcoal, as has been supposed. This suggestion seems to be confirmed by the recent discovery of the effect produced on heated iron by the ferro-cyanide of potassium, converting it readily into steel, at least at the surface, in the same manner as when heated in animal carbon.

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* Derived from *κυανος*, *blue*, and *γενναν*, *to generate*, because it is an ingredient of Prussian blue.

SECTION V.

SULPHUR.

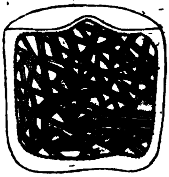
Symbol S; Equivalent 16.1.

474. SULPHUR occurs as a mineral production in some parts of the earth, particularly in the neighborhood of volcanoes, as in Italy and Sicily. It exists much more abundantly in combination with several metals, such as silver, copper, antimony, lead, and iron. It is procured in large quantity by exposing iron pyrites to a red heat in close vessels.

It is also found in many organic bodies, as in the egg, in the hair, the hoofs, and horns of animals, and in the seeds of the black mustard.

475. Sulphur is a brittle solid of a greenish-yellow color, emits a peculiar odor when rubbed, and has little taste. It is a non-conductor of electricity, and is excited negatively by friction. Its specified gravity is 1.99. Its point of fusion is 226°; between 230° and 280° it possesses the highest degree of fluidity, is then of an amber color, and if cast into cylindrical moulds, forms the common roll sulphur of commerce. It begins to thicken near 320°, and acquires a reddish tint; and at temperatures between 428° and 482°, it is so tenacious that the vessel may be inverted without causing it to change its place. From 482° to its boiling point it again becomes liquid, but never to the same extent as when at 248°. When heated to at least 428°, and then poured into water, it becomes a ductile mass, which may be used for taking the impression of seals. After some time it changes into its ordinary state.

Fig. 74.



476. Fused sulphur has a tendency to crystalize in cooling. A crystaline arrangement is preceptible in the centre of common roll sulphur; and by good management regular crystals may be obtained. For this purpose several pounds of sulphur should be melted in an earthen crucible; and when partially cooled, the outer solid crust should be pierced, and the crucible quickly inverted, so that the inner and as yet fluid parts may gradually flow out. On breaking the solid mass, when quite cold, crystals of sulphur will be found in its interior, the primary form of which is the oblique rhombic prism.

477. Sulphur is very volatile. It begins to rise slowly in vapor even before it is completely fused. At 550° or 600° it volatilizes rapidly, and condenses again unchanged in close vessels. Common sulphur is purified by this process; and if the sublimation be conducted slowly, the sulphur collects in the

receiver in the form of detached crystaline grains, called *flowers of sulphur.* In this state, however, it is not quite pure: for the oxygen of the air within the apparatus combines with a portion of sulphur during the process, and forms sulphurous acid. The acid may be removed by washing the flowers repeatedly with water.

The density of sulphur vapor is about 6.65; and if it could exist at the temperature of 60°, 100 cubic inches under a barometric pressure of 30, would weigh 206.177 grains.

478. Sulphur is insoluble in water, but dissolves readily in boiling oil of turpentine, and in other oils. Chloride of sulphur and sulphuret of carbon also dissolve it; and from all the solutions it may be obtained in crystals, the primary form of which is the rhombic octohedron. It is therefore dimorphous (362).

Sulphur is also soluble in alcohol, if both substances are brought together in the form of vapor. The sulphur is precipitated from the solution by the addition of water.

When sulphur is heated in the open air to 300° or a little higher, it kindles spontaneously, and burns with a faint blue light. In oxygen gas its combustion is far more vivid; the flame is much larger, and of a bluish-white color. Sulphurous acid is the product in both instances;—no sulphuric acid is formed even in oxygen gas unless moisture be present.

479. Sulphur is used extensively in the arts, and in medicine. It is employed in the manufacture of gunpowder, sulphuric acid, the different kinds of matches, vermilion, &c., and for taking impressions of seals. In medicine, it is used in cutaneous diseases, and as a cathartic and alterative.

SULPHUR AND OXYGEN.

There are four compounds of sulphur and oxygen, all of which are acids. They are as follows:

	Sulphur.	*Oxygen.*	*Equiv.*	*Symbols.*
Hyposulphurous acid	2 eq. +	2 eq.	48.2	S_2O_2
Sulphurous acid	1 eq. +	2 eq.	32.1	SO_2
Hyposulphuric acid	2 eq. +	5 eq.	70.2	S_2O_5
Sulphuric acid	1 eq. +	3 eq.	40.1	SO_3

According to Thomson there is still another acid compound of these substances, composed of sulphur two equivalents and oxygen one equivalent.

480. *Hyposulphurous Acid.*—This acid may be formed either by digesting sulphur in a solution of any sulphite, or by transmitting a current of sulphurous acid into a solution of sulphuret of calcium or strontium. A convenient solution for this purpose is made by boiling 3 parts of slaked lime and 1 of sulphur, with 20 parts of water, for one hour, and decanting the clear liquid from the undissolved portions; but when this solution is used, an abundant deposite of sulphur takes place.

This compound is properly called hyposulphurous acid, because the proportion of oxygen it contains, compared with the sulphur, is less than in sulphurous acid, but it is to be observed that its equivalent, or the quantity of it required to neutralize one eq. of an alkali, is not 24.1, but 48.2.

481. Hyposulphurous acid cannot exist permanently in a free state. On decomposing a hyposulphite by any stronger acid, such as sulphuric or hydrochloric, the hyposulphurous acid, at the moment of quitting the base resolves itself into sulphurous acid and sulphur. The solution of all the neutral hyposulphites has the peculiar property of dissolving recently precipitated chloride of silver in large quantity, and forming with it a liquid of an exceedingly sweet taste. On this property is founded their use in photography (157).

482. *Sulphurous Acid.*—Pure sulphurous acid, at the common temperature and pressure, is a colorless transparent gas, which was first obtained in a separate state by Priestley. It is the sole product when sulphur is burned in air or dry oxygen gas, and is the cause of the peculiar odor emitted by that substance during its combustion.

483. It may also be prepared by depriving sulphuric acid of one equivalent of its oxygen, which may be done by its action on various substances, and particularly upon the metals. One portion of sulphuric acid yields oxygen to the metal, and is thereby converted into sulphurous acid; while the metallic oxide, at the moment of its formation, unites with some of the undecomposed sulphuric acid. The best method of obtaining pure sulphurous acid gas, is by putting two parts of mercury and three of sulphuric acid into a glass retort, the beak of which is received under mercury, and heating the mixture by a lamp.

484. This gas is readily distinguished from all others by its suffocating, pungent odor. All burning bodies, when immersed in it, are extinguished without setting fire to the gas itself. It is fatal to all animals which are placed in it. A violent spasm of the glottis takes place, by which the entrance of the gas into the lungs is prevented; and even when diluted with air, it excites cough, and causes a peculiar uneasiness about the chest.

The specific gravity of gaseous sulphurous acid is 2.21; the weight of 100 cubic inches therefore is 68.55 grains.

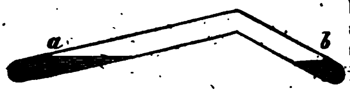
Recently boiled water dissolves about 33 times its volume of sulphurous acid at 60° and 30 inches of the barometer, forming a solution which has the peculiar odor of that compound, and from which the gas, unchanged in its properties, may be expelled by ebullition.

485. Sulphurous acid has considerable bleaching properties. It reddens litmus paper, and then slowly bleaches it. Most vegetable coloring matters, such as those of the rose and violet, are speedily removed, without being first reddened. It is remarkable that the coloring principle is not destroyed; for it may be restored either by a stronger acid or by an alkali.

Though sulphurous acid cannot be made to burn by the approach of flame, it has a very strong attraction for oxygen, uniting with it under favorable circumstances, and forming sulphuric acid. The presence of moisture is essential to this change. A mixture of sulphurous acid and oxygen gases, if quite dry, may be preserved over mercury for any length of time without chemical action. But if a little water be admitted, the sulphurous acid gradually unites with the oxygen, and sulphuric acid is generated. The facility with which this change ensues is such that a solution of sulphurous acid in water cannot be preserved, except atmospheric air be carefully excluded. The solutions of metals which have a weak affinity for oxygen, such as gold, platinum, and mercury, are completely decomposed by it, those substances being precipitated in the metallic form. Nitric acid converts it instantly into sulphuric acid by yielding some of its oxygen. Peroxide of manganese causes a similar change, and is itself converted into protoxide of manganese, which unites with the resulting sulphuric acid.

486. Sulphurous acid is converted into a liquid by a pressure of two atmospheres when the temperature is at 45°, and by the ordinary pressure at 0°. If the temperature is raised it enters into ebullition at 14°; but allowed to evaporate spontaneously, intense cold is produced, sufficient even to freeze mercury and liquefy ammonia, under the usual pressure of the atmosphere only.

Fig. 75.



487. A little of the liquid may be obtained very easily by putting a small quantity of mercury and sulphuric acid in a bent tube, as represented in figure 75, sealing it hermetically, and supplying heat to the extremity *a*, which contains the materials, while the other *b* is kept cool by means of ice or the evaporation of ether. The liquid will be soon found to collect in the cool part of the tube.

488. *Hyposulphuric Acid.*—This acid is formed by transmitting a current of sulphurous acid gas through water containing peroxide of manganese in fine powder.

Hyposulphuric acid reddens litmus paper, has a sour taste, and forms neutral salts with alkalies. It has no odor, by which circumstance it is distinguished from sulphurous acid. It cannot be confounded with sulphuric acid; for it forms soluble salts with baryta, strontia, &c., with which sulphuric acid forms insoluble compounds. It cannot be obtained free from water. The greatest density of the hydrous acid is 1.35.

489. *Sulphuric Acid.*—Sulphuric acid, or *oil of vitriol*, as it is often called, was discovered by Basil Valentine, towards the close of the 15th century. It is procured for the purposes of commerce by two methods. One of these has been long pursued in the manufactory at Nordhausen, in Germany, and consists in decomposing protosulphate of iron (green vitriol) by heat. This salt contains 6 equivalents of water of crystalization; and when strongly dried by the fire, it crumbles down

into a white powder, which still contains 1 equivalent of water. On exposing this dried protosulphate to a red heat, its acid is wholly expelled, the greater part passing over unchanged into the receiver in combination with the water of the salt. Part of the acid, however, is resolved by the strong heat employed in the distillation into sulphurous acid and oxygen. Peroxide of iron is the sole residue.

490. The acid, as procured by this process, is a dense, oily liquid of a brownish tint. It emits copious white vapors on exposure to the air, and is hence called *fuming sulphuric acid.* Its specific gravity is stated at 1.896 and 1.90. It consists of 80.2 parts or 2 equivalents of anhydrous acid, and 9 parts or 1 equivalent of water.

On putting this acid into a glass retort, to which a receiver surrounded by snow is securely adapted, and heating it gently, a transparent, colorless vapor passes over, which condenses into a white crystaline solid. This substance is pure anhydrous sulphuric acid. It is tough and elastic; liquefies at 66°, and boils at a temperature between 104° and 122°, forming, if no moisture is present, a transparent vapor. Exposed to the air, it unites with watery vapor, and flies off in the form of dense white fumes. The residue of the distillation is no longer fuming, and is in every respect similar to the common acid of commerce.

491. The other process for forming sulphuric acid of commerce, referred to above, which is the one practised exclusively in England and in this country, is by burning sulphur previously mixed with one-eighth its weight of nitrate of potassa. The mixture is burned in a furnace, so contrived that the current of air which supports the combustion conducts the gaseous products into a large leaden chamber, the bottom of which is covered to the depth of several inches with water.

Numerous and complicated changes take place during the combustion of the sulphur, by which oxygen from the air is transferred to the sulphur, converting it into this acid. The water is designed chiefly to absorb the vapors of sulphuric acid as they are formed, but watery vapor is also necessary in the chemical changes that occur.

The water in the chamber is allowed to remain unchanged until it has acquired a specific gravity of about 1.6, when it is removed and concentrated by evaporation, first in leaden cisterns, and afterwards in glass or platinum retorts.

Sulphuric acid prepared in this manner is a dense, colorless, oily fluid, which boils at 620°, and has a specific gravity, in its most concentrated form, of 1.85. Mitscherlich found the density of its vapor to be 3. It is one of the strongest acids with which chemists are acquainted, and when undiluted is powerfully corrosive. It decomposes all animal and vegetable substances by the aid of heat, causing deposition of charcoal and formation of water. It has a strong, sour taste, and reddens litmus paper, even though greatly diluted. It unites with alkaline substances, and separates all other acids more or less completely from their combinations with the alkalies.

492. In a very concentrated state it dissolves small quantities of sulphur, and acquires a blue, green, or brown tint. Tellurium and selenium are also sparingly dissolved, the former causing a crimson, and the latter a green color. By dilution with water, these substances subside unchanged; but if heat is applied, they are oxydized at the expense of the acid, and sulphurous acid gas is disengaged. Charcoal also appears soluble to a small extent in sulphuric acid, communicating at first a pink, and then a dark reddish-brown tint.

This acid, prepared as above described, by the combustion of sulphur in leaden chambers, is apt to be contaminated by a little sulphate of potassa and lead, from which it may be purified by careful distillation. Recently, instead of sulphur, iron pyrites (see IRON) has been much used in its manufacture, and it has in consequence frequently been found to contain arsenic and selenium.

493. Sulphuric acid has a very great affinity for water, and unites with it in every proportion. The combination takes place with production of intense heat. When four parts by weight of the acid are suddenly mixed with one of water, the temperature of the mixture rises to 300°. By its attraction for water, it causes the sudden liquefaction of snow; and if mixed with it in due proportion, intense cold is generated. It absorbs watery vapor with avidity from the air, and on this account is employed in the process for freezing water by its own evaporation. The action of sulphuric acid in destroying the texture of the skin, in forming ethers, and in decomposing animal and vegetable substances in general, seems dependent on its affinity for water.

In order to determine the strength of liquid sulphuric acid, it is sufficient to know that every 53.42 parts of pure carbonate of soda will neutralize precisely 40.1 parts of real sulphuric acid. When very great accuracy is not desired, it will be sufficient to find the specific gravity according to the tables given in books.

494. Sulphuric acid of commerce freezes at —15°. Diluted with water so as to have a specific gravity of 1.78, it congeals even above 32°, and remains in the solid state till the temperature rises to 45°. When mixed with rather more than its weight of water, its freezing point is lowered to —36°.

Chemists possess an unerring test of the presence of sulphuric acid. If a solution of chloride of barium is added to a liquid containing sulphuric acid, it causes a white precipitate, sulphate of baryta, which is characterized by its insolubility in acids and alkalies.

Sulphuric acid occasionally occurs free in nature, as at Byron, Genesee County, New York, but such cases are rare.—(*New York Geological Report for* 1840.).

495. Sulphuric acid is applied in the arts and in the laboratory to very many important uses; as, in the preparation of the other acids, the extraction of soda from common salt, the manufacture of alum, sulphate of iron, chlorine, &c. It is also used as a solvent for indigo, and in the various manufactures of the metals.

SULPHUR AND HYDROGEN.

Sulphur combines with hydrogen in two proportions, and the resulting compounds are constituted as follows:

	Hydrogen.	*Sulphur.*	*Equiv.*	*Symbols.*
Hydrosulphuric acid	1 eq. +	1 eq.	17.1	HS
Persulphuretted hydrogen	1 eq. +	2 eq.	33.2	HS_2

496. *Hydrosulphuric Acid.*—This compound is also known by the name of sulphuretted hydrogen, but as it possesses distinct acid properties, it is with propriety ranked among the acids.

It may be prepared by several processes; but for common purposes it may most readily be formed by the action of diluted sulphuric acid upon the protosulphuret of iron. The changes that take place during this process are easily understood; they are represented by the following formula: $FeS+SO_3+HO=FeO, SO_3+HS$.

From this it appears that when a single atom of each of the three substances, protosulphuret of iron, sulphuric acid, and water, come in contact, the particle of water is decomposed, its oxygen immediately combining with the iron, and its hydrogen with the sulphur which was before united with the iron. Thus a particle of protoxide of iron and another of hydrosulphuric acid are formed simultaneously, the latter of which escapes in the gaseous form, while the former combines with the sulphuric acid to constitute sulphate of the protoxide of iron, which remains in solution.

497. A sulphuret of iron may be procured for the purpose, either by igniting common iron pyrites, by which means nearly half of its sulphur is expelled, or by exposing to a red heat a mixture of two parts of iron-filings and rather more than one part of sulphur. The materials should be placed in a common earthen or cast-iron crucible, and be protected as much as possible from the air during the process. The sulphuret procured from iron-filings and sulphur always contains some uncombined iron, and, therefore, the gas obtained from it is never quite pure, being mixed with a little free hydrogen. This, however, for many purposes, is immaterial.

498. Hydrosulphuric acid is a colorless gas, which reddens moist litmus paper feebly, and is distinguished from all other

gaseous substances by its offensive taste and odor, which is similar to that of putrefying eggs, or the water of sulphurous springs. Under a pressure of 17 atmospheres, at 50°, it is compressed into a limpid liquid, which resumes the gaseous state as soon as the pressure is removed. To animal life it is very injurious. According to Dupuytren and Thenard, the presence of $\frac{1}{1500}$th of this gas is instantly fatal to a small bird; $\frac{1}{1000}$th killed a middle-sized dog; and a horse died in an atmosphere which contained $\frac{1}{250}$th of its volume.

Hydrosulphuric acid extinguishes all burning bodies; but the gas takes fire when a lighted candle is immersed in it, and burns with a pale blue flame. Water and sulphurous acid are the products of its combustion, and sulphur is deposited. With oxygen gas it forms a mixture which detonates by the application of flame or the electric spark.

Its specific gravity is 1.18; and 100 cubic inches, therefore, weigh 36.49 grains.

Recently boiled water absorbs its own volume of hydrosulphuric acid, becomes thereby feebly acid, and acquires the peculiar odor and taste of sulphurous springs. The gas is expelled without change by boiling the water.

Water naturally impregnated with hydrosulphuric acid issuing from the earth constitutes *sulphur springs*, of which there are many in this and other countries. The hydrosulphuric acid is probably formed by the decomposition of metallic sulphurets.

499. The elements of hydrosulphuric acid may easily be separated from one another. A solution of the gas cannot be preserved in an open vessel, because its hydrogen unites with the oxygen of the atmosphere, and sulphur is deposited. When mixed with sulphurous acid, both compounds are decomposed, water is generated, and sulphur set free. On pouring into a bottle of the gas a little fuming nitric acid, mutual decomposition ensues, a bluish-white flame frequently appears, sulphur and nitrous acid fumes come into view, and water is generated. Chlorine, iodine, and bromine decompose it, with separation of sulphur, and formation of hydrochloric, hydriodic, and hydrobromic acids. An atmosphere charged with hydrosulphuric acid gas may be purified by means of chlorine in the space of a few minutes.

Hydrosulphuric acid gas is readily distinguished from other gases by its odor, by tarnishing silver, with which it forms a sulphuret, and by the character of the precipitate which it produces with solutions of arsenious acid, tartar emetic, and salts of lead.

The most delicate test of its presence, when diffused in the air, is moist carbonate of oxide of lead spread on white paper, which is instantly blackened by it.

An amusing experiment is performed by making some drawings upon white paper with solution of some colorless metallic salt, as acetate of lead, which will remain invisible till introduced into an atmosphere containing hydrosulphuric acid gas, when they at once become of a dark brown or black color. If the drawings have become dry, the *back* of the paper should be moistened with a wet sponge before using them.

500. *Persulphuret of Hydrogen.*—This compound also possessing acid properties was discovered by Scheele. It is properly bisulphuret of hydrogen. It is not a stable compound, being easily decomposed into sulphur and hydrosulphuric acid. At common temperatures it is a viscid liquid of a yellow color, and possesses a density of about 1.77.

Regarded as an acid the name *hydropersulphuric acid* has been proposed for it.

SULPHUR AND CARBON.

There is only one compound of these substances known, the

	Carbon.	*Sulphur.*	*Equiv.*	*Symbol.*
Bisulphuret............	1 eq. +	2 eq......	38.32......	CS_2.

501. *Bisulphuret of Carbon.*—This compound may be obtained by heating in close vessels native bisulphuret of iron (iron pyrites) with one-fifth of its weight of well-dried charcoal; or by transmitting the vapor of sulphur over fragments of charcoal heated to redness in a tube of porcelain. The compound, as it is formed, should be conducted by means of a glass tube into cold water, at the bottom of which it is collected. To free it from moisture and adhering sulphur, it should be distilled at a low temperature in contact with chloride of calcium.

Bisulphuret of carbon is a transparent colorless liquid, which is remarkable for its high refractive power. Its specific gravity is 1.27. It has an acid, pungent, and somewhat aromatic taste, and a very fetid odor. It is exceedingly volatile;—its vapor at 63.5° supports a column of mercury 7.36 inches long; and at 110° it enters into brisk ebullition. From its great volatility it may be employed for producing intense cold.

If the bulb of a spirit-thermometer be coated with fine lint and moistened with this substance, and then placed under the receiver of an air-pump, by working the machine rapidly it may be made in a minute or two to sink to —82°.

In consequence of its rapid evaporation it was formerly called *alcohol of sulphur;* the name *sulphocarbonic acid* has also been applied to it.

502. Bisulphuret of carbon is very inflammable, and kindles in the open air at a temperature scarcely exceeding that at which mercury boils. It burns with a pale blue flame. Admitted into a vessel of oxygen gas, so much vapor rises as to form an explosive mixture; and when mixed in like manner with binoxide of nitrogen, it forms a combustible mixture,

which is kindled on the approach of a lighted taper, and burns rapidly, with a large greenish-white flame of dazzling brilliancy. It dissolves readily in alcohol and ether, and is precipitated from the solution by water. It dissolves sulphur, phosphorus, and iodine, and the solution of the latter has a beautiful pink color. Chlorine decomposes it, with formation of chloride of sulphur.

This substance in many of its relations resembles carbonic acid, with which it is in fact exactly equivalent in composition, the two atoms of oxygen of the carbonic acid (CO_2) being replaced by two atoms of sulphur (CS_2).

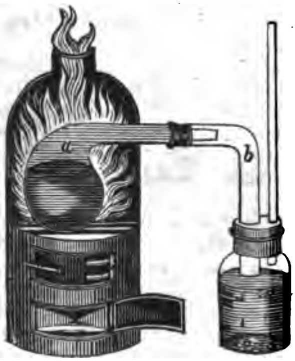
SECTION VI.

PHOSPHORUS.

Symbol P; Equivalent 15.7.

503. Phosphorus (φωςφορος, from φως, *light*, and φερειν, *to carry*), so called from its property of shining in the dark, was discovered about the year 1669, by Brandt, an alchymist of Hamburg. It was originally prepared from urine; but Scheele afterwards described a method of obtaining it from bones, which is now generally practised. The bones are first ignited in an open fire till they become white, so as to destroy their animal matter, and burn away the charcoal derived from it, in which state they contain nearly $\frac{4}{5}$th of phosphate of lime. They are then reduced to a fine powder, and digested for a day or two with half their weight of strong sulphuric acid, with the addition of so much water as will give the consistence of a thin paste. Decomposition of the phosphate of lime is thus effected, and two new salts formed, the sparingly soluble sulphate, and a soluble superphosphate of lime. The latter is then dissolved in warm water, and the solution, after being separated by filtration from the sulphate of lime, is evaporated to the consistence of syrup, mixed with a fourth of its weight of powdered charcoal, and introduced into an earthen retort *a*, which is placed in a furnace, as represented in figure 76. To the neck of the retort a copper tube *b* is adapted, the other extremity of which dips

Fig. 76.



a little into the surface of water contained in a bottle which answers as a receiver. Any gas that forms escapes by a second tube inserted in the stopper of the bottle. The heat is gradually raised, and the phosphorus passes over in vapor through the copper tube and is condensed in the water. When first obtained it is usually of a reddish-brown color, owing to the presence of phosphuret of carbon formed during the process. It may be purified by fusion in hot water, and being pressed while liquid through chamois-leather, or by a second distillation.

504. In this process the oxygen of that part of the phosphoric acid which constituted superphosphate, unites with charcoal, giving rise to carbonic acid and carbonic oxide gases; and phosphate of lime in the state of bone earth, together with redundant charcoal, remains in the retort. The lime acts an important part in fixing the phosphoric acid, which, if not so combined, would distil over before the heat was high enough for its decomposition.

505. Pure phosphorus is transparent and almost colorless. At common temperatures it is a soft solid of specific gravity 1.77; and may easily be cut with a knife. At 108° it fuses, and at 550° is converted into vapor, which, according to Dumas, has a density of 4.35. It is soluble by the heat in naphtha, in fixed and volatile oils, in the chloride of sulphur, sulphuret of carbon, and sulphuret of phosphorus. On its cooling from solution in the latter, Mitscherlich obtained it in regular dodecahedral crystals. By the fusion and slow cooling of a large quantity of phosphorus, it has been obtained in very fine crystals, of an octohedral form, and as large as a cherry-stone. Thenard has remarked that when phosphorus is fused at 150°, and suddenly cooled by being plunged into cold water, it appears black; but by fusion and slow cooling it recovers its original aspect.*

506. Phosphorus is exceedingly inflammable. Exposed to the air at common temperatures, it undergoes slow combustion, emits a white vapor of a peculiar alliaceous odor, appears distinctly luminous in the dark, and is gradually consumed. On this account, phosphorus should always be kept under water. The disappearance of oxygen which accompanies these changes is shown by putting a stick of phosphorus in a jar full of air, inverted over water. The volume of the gas gradually diminishes; and if the temperature of the air is at 60°, the whole of the oxygen will be withdrawn in the course of 12 or 24 hours. The residue is nitrogen gas, containing about $\frac{1}{40}$th of its bulk of the vapor of phosphorus. It is remarkable that the slow

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* Phosphorus is manufactured in large quantities in some parts of Europe. In Paris alone it is computed about 200,000 pounds are made annually.—*Kane.*

combustion of phosphorus does not take place in pure oxygen, unless its temperature be about 80°. But if the oxygen be diluted with nitrogen, hydrogen, or carbonic acid gas, the oxydation occurs at 60°; and it takes place at temperatures still lower in a vessel of pure oxygen, rarefied by diminished pressure.

A very slight degree of heat is sufficient to inflame phosphorus in the open air. Gentle pressure between the fingers, friction, or a temperature not much above its point of fusion, kindles it readily. It burns rapidly even in the air, emitting a splendid white light, and causing intense heat. Its combustion is far more rapid in oxygen gas, and the light proportionally more vivid.

507. There is some doubt concerning the proper atomic weight of phosphorus, some believing it to be 15.7, as stated in the table (page 136), and others considering it 31.4, which is double the former number. The editor of the last (7th) edition of Dr. Turner's work, whom we follow, continues still to use the former number (15.7), but Kane adopts the latter (31.4).

Phosphorus is not much used in the arts. Matches are however made of it, which ignite by slight friction. For this purpose, it is dissolved in glue. In the chemical laboratory it is of very important service, and is some used in medicine.

PHOSPHORUS AND OXYGEN.

There are four compounds of phosphorus and oxygen, all of which except the first are acids. They are as follows:

	Phosphorus.		*Oxygen.*	*Equiv.*	*Symbols.*
Oxide of phosphorus	3 eq.	+	1 eq.	55.1	P_3O
Hypophosphorous acid	2 eq.	+	1 eq.	39.4	P_2O
Phosphorous acid	2 eq.	+	3 eq.	55.4	P_2O_3
Phosphoric acid	2 eq.	+	5 eq.	71.4	P_2O_5

508. *Oxide of Phosphorus.*—This oxide may be found by forcing a jet of oxygen upon phosphorus melted under hot water; and the red matter left where phosphorus is burned in the open air, is probably of the same nature. Oxide of phosphorus is permanent in the air, requiring a red heat to ignite it, but takes fire spontaneously in chlorine. It is probably the same substance which forms upon sticks of phosphorus exposed to the action of light in water.

509. *Phosphorous Acid.*—When phosphorus is burned in air highly rarefied, imperfect oxydation ensues, and phosphoric and phosphorous acids are generated, the latter being obtained in the form of a white volatile powder. In this state it is anhydrous. It dissolves readily in water, has a sour taste, and smells somewhat like garlic. The solution of phosphorous acid absorbs oxygen slowly from the air, and is converted into phosphoric acid. From its tendency to unite with an additional quantity of oxygen, it is a powerful deoxydizing agent; and hence, like sulphurous acid, precipitates mercury, silver, platinum, and gold, from their saline combinations in the metallic form. Nitric acid converts it into phosphoric acid.

Phosphorous acid is also generated during the slow oxydation of phosphorus in atmospheric air. The product which likewise contains phosphoric acid, attracts moisture from the air, and forms an oil-like liquid, which was formerly called *phosphatic acid*, from the erroneous opinion that it is a distinct substance.

110. *Phosphoric Acid.*—This acid is best prepared from the superphosphate of lime, obtained from calcined bones, in the manner described above (503). For this purpose the superphosphate should be boiled for a few minutes with excess of carbonate of ammonia. The lime is thus precipitated as a carbonate, and the solution contains phosphate, together with a little sulphate of ammonia. The liquid, after filtration, is evaporated to dryness, and then ignited in a platinum crucible, by which means the ammonia and sulphuric acid are expelled, and the phosphoric acid remains behind melted, but on cooling it solidifies into a colorless glass, the *glacial phosphoric acid.*

Phosphoric acid may also be prepared by igniting a small piece of phosphorus in air under a receiver. By this process it is deposited in white flakes on the inside of the glass and on the plate which supports it.

511. This acid has a strong affinity for water, with which it forms three distinct compounds, *phosphates of water*, the constitution of which is as follows:

Monobasic phosphate of water	P_2O_5, HO
Bibasic phosphate of water	P_2O_5, 2HO
Tribasic phosphate of water	P_2O_5, 3HO

A solution of phosphoric acid in water may contain any one of these three phosphates of water, and when neutralized by bases, may therefore produce totally different salts. The particular phosphate of water contained in solution in a given case will depend upon the manner in which it has been prepared. It is necessary therefore that these compounds of water should be well understood.

512. *Monobasic Phosphate of Water.*—This is simply phosphate of water, composed of 1 equivalent of phosphoric acid and 1 equivalent of water. Its solution is strongly acid, and if boiled, rapidly changes to bibasic or tribasic phosphate. It throws down albumen in white curds, and with nitrate of silver gives a greyish-white precipitate. When neutralized by bases it forms salts which contain but one atom of base; thus let X represent an atom of the base, the formula for the salt will be P_2O_5, X. This form of the acid has been called *metaphosphoric acid.*

513. *Bibasic Phosphate of Water.*—Bibasic phosphate of water is only another term for disphosphate of water, or a compound of phosphoric acid and water, containing 1 equivalent of the acid to 2 eq. of water. It may be prepared by decomposing the diphosphate of lead by hydrosulphuric acid. In

solution with cold water it gradually changes to triphosphate of water; in boiling water the change takes place with rapidity.

Neutralized with ammonia it gives a white granular precipitate with nitrate of silver, by which it is characterized. Strong bases, as the alkalies and metallic oxides, readily displace the water, and combining with the acid, produce disalts, whose formula (X, as before, representing an equivalent of the base), will be P_2O_5, 2X. It is however to be remembered, that these salts may contain only one equivalent of fixed base, the other being water; the formula will then be P_2O_5, HO, X. This water requires a red heat to expel it, while the water of crystalization that may be present will require but a moderate heat to drive it off. *Pyrophosphoric acid* is the term formerly applied to this form of the acid.

514. *Tribasic Phosphate of Water.*—This is the form of phosphoric acid contained in the class of phosphates most generally known. It is in fact a triphosphate of water; and is characterized by not precipitating albumen, by giving (if previously neutralized with ammonia), with nitrate of silver a yellow precipitate, and by combining with three equivalents of the bases, when fully neutralized. If we let X represent an equivalent of base, as before, the formula for its salts when the acid is fully neutralized will be, P_2O_5, 3X.

In the tribasic phosphates, however, it frequently occurs that there is but a single equivalent of fixed base, the other two being water. Thus one tribasic phosphate of soda is P_2O_5, 2HO, NaO. Or there may be present 2 equivalents of soda and 1 of water, and then the formula will be P_2O_5, HO, 2NaO. The solution of the salt in this case possesses an acid reaction.

PHOSPHORUS AND HYDROGEN.

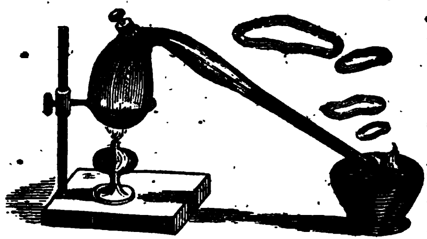
There are several compounds of phosphorus and hydrogen, but one only will be described in this work, the common

	Phosphorus.	Hydrogen.	Equiv.	Symbol.
Phosphuretted hydrogen..	2 eq. +	3 eq......	34.4.....	P_2H_3

515. *Phosphuretted Hydrogen.*—There are several modes of preparing this substance, which is always gaseous; but two methods are chiefly adopted. The first consists in heating phosphorus in solution of caustic potassa or milk of lime; by which water is decomposed, giving its hydrogen to one portion of phosphorus to form phosphuretted hydrogen, and its oxygen to another portion to produce hypophosphorous acid. The other method is to heat hydrated phosphorous acid, by which water is decomposed and phosphoric acid and phosphuretted hydrogen produced.

The gas prepared by these different methods possesses some very different properties. When prepared by the first

Fig. 77.



method, each bubble, as it escapes into the air from the retort through the water of the pneumatic cistern, takes fire spontaneously, and burns with a beautiful white flame, forming a ring of phosphoric acid smoke, which widening as it rises may ascend to a considerable height before it is broken up, if the air of the apartment is perfectly still. If the bubbles of gas are allowed to ascend into a receiver of oxygen gas, the combustion is attended with explosion.

516. Prepared by the second process, spontaneous combustion does not take place, as in the other case; but if set on fire, the gas burns with the same appearances.

On analysis, both varieties give exactly the same result. Prepared by either method, the gas is transparent and colorless, and of an offensive odor and bitter taste.* Its specific gravity is 1.18, and 100 cubic inches weigh 36.75 grains. It is not a supporter of combustion, and is destructive to animal life. Water absorbs it in small quantities.

517. The two varieties of this gas were formerly considered isomeric; but it is now believed the apparent difference of properties arises from the presence of a minute quantity of some foreign substance accidentally occasioned in one or the other by the peculiar method of preparation. Thus it is found that the spontaneously inflammable variety loses this property if a small quantity of the vapor of ether or of the essential oils is present; and, on the other hand, the second variety becomes spontaneously inflammable by the introduction of a very minute quantity of nitrous acid or nitric oxide.

PHOSPHORUS AND SULPHUR.

518. *Sulphuret of Phosphorus.*—Phosphorus and sulphur combine when sulphur is brought in contact with fused phosphorus, but in proportions which have not been determined. The experiment should never be made with more than 30 or 40 grains of phosphorus, nor the temperature raised

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* Those who have observed the odor of this gas, and that of the liquid emitted by the American skunk (*Mephitis Americana*) when disturbed, cannot but have noticed the resemblance between them; which seems to render it probable that the fluid emitted by the skunk contains, in solution, a portion of the gas, or some other nearly related compound of the same substances. This is rendered still more probable from the fact, that the fluid, when emitted by the animal in the dark, is distinctly *phosphorescent.*—*See Godman's Natural History, vol.* 1, 289. *Philadelphia Edition*, 1829.

above 160°; and, even then explosions will sometimes take place. This compound is exceedingly combustible, as we should judge from the nature of its elements. It is much more fusible than phosphorus.

Phosphorus combines with nitrogen, but the compounds are not here described.

SECTION VII.

BORON.

Symbol B; Equivalent 10.9.

519. BORON was first obtained by Davy in 1807, by exposing boracic acid to the action of a powerful galvanic battery, and afterwards by Gay-Lussac and Thenard, by heating boracic acid with potassium. For ordinary experiments, it may be obtained of sufficient purity by heating a small portion of borax in fine powder, with one-tenth of its weight of charcoal, in a gun-barrel, and washing the powder obtained with hydrochloric acid and water. The borax should be first heated, to expel all the water it contains.

Boron is a dark olive-colored substance, which has neither taste nor smell, and is a non-conductor of electricity. It is insoluble in water, alcohol, ether, and oils. It does not decompose water whether hot or cold. It bears intense heat in close vessels, without fusing or undergoing any other change except a slight increase of density. Its specific gravity is about twice as great as that of water. It may be exposed to the atmosphere at common temperatures without change; but if heated to 600° it suddenly takes fire, oxygen gas disappears, and boracic acid is generated. It also passes into boracic acid when heated with nitric acid, or with any substance that yields oxygen with facility.

BORON AND OXYGEN.

There is but one compound of these substances known, which possesses acid properties, and is constituted as follows:

	Boron.		*Oxygen.*	*Equiv.*	*Symbol.*
Boracic acid	1 eq.	+	3 eq.	34.9	BO_3

520. *Boracic Acid.*—This acid is found as a natural product in the hot springs of Lipari, and in those of Sasso in the Florentine territory. It is a constituent of several minerals, among which the datholite and boracite may in particular be mentioned. It occurs much more abundantly under the form of borax, a native compound of boracic acid and soda. It is prepared for chemical purposes by adding sulphuric acid to a solution of purified borax in about four times its weight of

boiling water, till the liquid acquires a distinct acid reaction. The sulphuric acid unites with the soda; and the boracic acid is deposited, when the solution cools, in a confused group of shining scaly crystals. It is then thrown on a filter, washed with cold water to separate the adhering sulphate of soda and sulphuric acid, and still farther purified by solution in boiling water and re-crystalization. But even after this treatment it is apt to retain a little sulphuric acid; and on this account, when required to be absolutely pure, it should be fused in a platinum crucible, and once more dissolved in hot water and crystalized.

521. Boracic acid in this state is a hydrate, which contains 43.62 per cent. of water, being a ratio of 34.9 parts or one equivalent of the anhydrous acid to 27 parts or three equivalents of water. This hydrate dissolves in 25.7 times its weight of water at 60°, and in 3 times at 212°. Boiling alcohol dissolves it freely, and the solution, when set on fire, burns with a beautiful green flame; a test which affords the surest indication of the presence of boracic acid. Its specific gravity is 1.48.

Boracic acid has no odor and but little taste, which is bitter rather than acid. It reddens litmus paper, and slightly changes the color of turmeric paper to brown, precisely like the alkalies.

Boron is not known to unite with any other of the substances heretofore described except hydrogen, with which it forms a gaseous compound of little importance.

SECTION VIII.

SILICON.

Symbol Si; Equivalent 22.51.

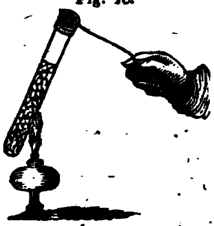
522. THAT silica, or, as it is now generally considered, silicic acid, is composed of a combustible substance united with oxygen, was demonstrated by Davy; but pure silicon, the base of silica, was first obtained by Berzelius in 1824.

It was first considered a metal, and called *silicium*, but is now generally ranked among non-metallic substances, and designated by the name at the head of this article.

523. To prepare silicon a somewhat complex substance is selected, the double fluoride of silicon and potassium, which is a white powder like starch.

When this compound is heated in a glass tube with potassium, by means of a spirit-lamp, the fluorine combines with the potassium, and the silicon is separated from the mass by washing with water. To have the silicon perfectly pure, several pre-

Fig. 78.



cautions are to be observed which need not here be detailed. Obtained in this manner, silicon is a powder of a dark nut-brown color, without the least trace of metallic lustre: and is a non-conductor of heat and electricity. It stains the fingers, and adheres to everything that comes in contact with it; and when heated in the atmosphere or oxygen gas, it takes fire and burns, with the formation of silicic acid.

In close vessels, silicon, like charcoal and boron, is capable of enduring a very high temperature without fusion, but is rendered harder and more compact. It is now incombustible, even when highly heated in the air or in oxygen gas, and is unaffected by the blowpipe, even in contact with chlorate of potassa. Its specific gravity is above that of sulphuric acid, since it readily sinks in it. Thomson supposes the change is produced by the expulsion of the hydrogen which was before united with it. Berzelius is of opinion that a change in the aggregation of the particles is produced by the heat.

SILICON AND OXYGEN.

The only compound of silicon and oxygen known is silica or silicic acid, which is composed as follows:

	Silicon.	*Oxygen.*	*Equiv.*	*Symbol.*
Silicic acid............	1 eq. +	3 eq....	46.5....	SiO_3

524. *Silicic Acid.*—This compound, known also by the names of *silica* and *siliceous earth*, exists abundantly in nature. It enters into the composition of most of the earthy minerals; and under the name of quartz rock, forms independent mountainous masses. It is the chief ingredient of sand-stones, flint, calcedony, rock-crystal, and other analogous substances. It may indeed be procured, of sufficient purity for most purposes, by igniting transparent specimens of rock-crystal, throwing them while red-hot into water, and then reducing them to powder.

Pure silicic acid, in this state, is a light white powder, which feels rough and dry when rubbed between the fingers, and is both insipid and inodorous. It is fixed in the fire, and very infusible; but fuses before the oxy-hydrogen blowpipe with greater facility than lime or magnesia.

In its solid form silicic acid is quite insoluble in water; but Berzelius has shown that, if presented to water while in the nascent state, it is dissolved in large quantity. On evaporating the solution gently, a bulky gelatinous hydrate separates, which is partially decomposed by a very moderate temperature, but does not part with all its water except at a red heat.

525. Silicic acid has no action on test paper; but in all its chemical relations, it manifests the properties of an acid, and displaces carbonic acid by the aid of heat from the alkalies. Its combinations with the fixed alkalies are effected by mixing pure sand with carbonate of potassa or soda, and heating the mixture to redness. During the process, carbonic acid is expelled; and a silicate of the alkali is generated. The nature of the product depends upon the proportions which are employed. On igniting one part of silicic acid with three of carbonate of potassa, a vitreous mass is formed, which is deliquescent, and may be dissolved completely in water; is therefore sometimes called *soluble glass*. The solution has been called *liquor silicum;* it has an alkaline reaction, and absorbs carbonic acid on exposure to the atmosphere, by which it is partially decomposed.

But if the proportion of silicic acid and alkali be reversed, a transparent brittle compound results, which is insoluble in water, is attacked by none of the acids excepting the hydrofluoric, and possesses the well-known properties of glass. Every kind of ordinary glass is a silicate, and all its varieties are owing to differences in the proportion of the constituents, to the nature of the alkali, or to the presence of foreign matters. Thus, green bottle glass is made of impure materials, such as river sand, which contains iron, and the most common kind of kelp or pearl ashes. Crown glass for windows is made of a purer alkali, and sand which is free from iron. Plate glass, for looking-glasses, is composed of sand and alkali in their purest state; and in the formation of flint glass, beside these pure ingredients, a considerable quantity of litharge or red lead is employed. A small portion of peroxide of manganese is also used, in order to oxydize carbonaceous matters contained in the materials of the glass; and nitre is sometimes added with the same intention. Ordinary flint glass contains 51.93 per cent. of silicic acid, 33.28 of oxide of lead, and 13.77 of potassa; proportions which correspond to 1 equivalent of potassa, 1 equivalent of oxide of lead, and nearly 4 equivalents of silicic acid. Flint glass, accordingly, is a double salt, consisting chiefly of bisilicate of potassa and bisilicate of oxide of lead.

526. Silica is applied in the arts to several important purposes, as in the manufacture of glass and porcelain ware. Mixed with hydrate of lime it constitutes common mortar, but united with it in certain proportions in the form of clay, it constitutes water cement, which is capable of hardening under water.

SECTION IX.

SELENIUM.

Symbol Se; Equivalent 39.6.

527. THIS substance was first discovered by Berzelius in 1818, who gave it its present name, from Σελήνη, *the moon.*

It was first detected by him in a manufactory of sulphuric acid, in which the sulphur used was obtained from the iron pyrites (a native compound of iron and sulphur), of Fahlun in Sweden. It is found combined with sulphur in some of the volcanic products of the Lipari islands, and also in union with several of the metals, as lead, silver, cobalt, mercury, and copper in the Hartz mountains. In the United States it has been discovered in one or two localities associated with iron pyrites. From these compounds it is obtained by a complicated process.

528. Selenium, at common temperatures, is a brittle, opaque solid, without taste or odor. It has a metallic lustre and the aspect of lead when in mass: but it is of a deep red color when reduced to powder. Its specific gravity is 4.32. At 212° it softens, and is then so tenacious that it may be drawn out into fine threads which are transparent, and appear red by transmitted light. It becomes quite fluid at a temperature somewhat above that of boiling water. It boils at about 650°, forming a vapor which has a deep yellow color, but is free from odor. It may be sublimed in close vessels without change, and condenses again into dark globules of a metallic lustre, or as a cinnabar-red powder, according as the space in which it collects is small or large. Berzelius at first regarded it as a metal; but, since it is an imperfect conductor of heat and electricity, it more properly belongs to the class of the simple non-metallic bodies.

Selenium is insoluble in water. It suffers no change from mere exposure to the atmosphere; but if heated in the open air, it combines readily with oxygen, and two compounds, oxide of selenium and selenious acid, are generated. If exposed to the oxydizing part of the blow-pipe flame, it tinges the flame with a light blue color, and exhales so strong an odor of decayed horse-radish, that $\frac{1}{50}$th of a grain is said to be sufficient to scent the air of a large apartment. By this character the presence of selenium, whether alone or in combination, may always be detected.

529. Selenium combines with oxygen in three proportions, forming an oxide and two acids, the selenious and selenic, the last of which is in composition and many of its properties exceedingly analogous to sulphuric acid; and the same resemblance is observed in the salts formed from these acids.

Selenium also enters into combination with hydrogen, sulphur, and phosphorus. With hydrogen it forms hydroselenic acid.

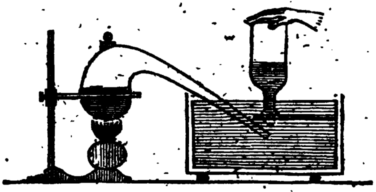
SECTION X.

CHLORINE.

Symbol Cl; Equivalent 35.42.

530. CHLORINE was discovered by Scheele, in the year 1774, and called by him *dephlogisticated marine acid.* For many years it was considered a compound of muriatic acid and oxygen, and was hence called *oxy-muriatic* acid, but at the present time it is universally regarded as a simple substance.

Fig. 79.



Chlorine gas is obtained by the action of hydrochloric acid on peroxide of manganese. The most convenient method of preparing it is by mixing concentrated hydrochloric acid, contained in a glass flask, with half its weight of finely powdered peroxide of manganese. Effervescence, owing to the escape of chlorine, takes place even in the cold; but the gas is evolved much more freely by the application of a moderate heat. It should be collected in inverted glass bottles filled with warm water; and when the water is wholly displaced by the gas, the bottles should be closed with a well-ground glass stopper. As some hydrochloric acid gas commonly passes over with it, the chlorine should not be considered quite pure, till after being transmitted through water.

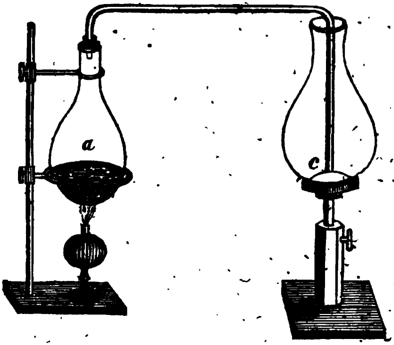
531. The theory of this process will be readily understood by first viewing the elements which act on each other, by means of the following formula: $MnO_2, 2HCl = MnCl, 2HO + Cl$.

It will be seen therefore that 2 equivalents of hydrochloric acid and 1 equivalent of peroxide of manganese yield 1 eq. of chloride of manganese, 2 of water, and 1 of free chlorine. The affinities which determine these changes are the mutual attraction of oxygen and hydrogen, and of chlorine and manganese.

By making use of the equivalent numbers of the several substances employed, we may easily determine the proportions of each to be used, in order to prepare a given quantity of chlorine.

When only a small quantity of the gas is desired, it may be collected sufficiently pure in the following manner: Let *a* be the vessel containing the materials from which the chlorine is evolved, *c* that in which it is to be collected. If the tube by which the gas enters is made to terminate near the bottom of

Fig. 80.



the receiver, as in fig. 80, the chlorine, in consequence of its greater specific gravity, will gradually lift the air and at length entirely displace it, just as a stream of water, introduced in a similar manner into a vessel of oil, would entirely expel it and take its place.

When it is an object to prepare chlorine at the cheapest rate, as for the purposes of manufacture, the preceding process is modified in the following manner:—Three parts of sea-salt are intimately mixed with one of peroxide of manganese, and to this mixture two parts of sulphuric acid, diluted with an equal weight of water, are added. By the action of sulphuric acid on sea-salt, hydrochloric acid is disengaged, which reacts, as in the former case, upon the peroxide of manganese; so that, instead of adding hydrochloric acid directly to the manganese, the materials for forming it are employed. In this process, however, the sulphates of soda and protoxide of manganese are generated, instead of chloride of manganese. The chemical changes that take place are exhibited in the formula which follows; the symbols on the left of the sign = representing the substances before the action takes place, those on the right, the results of the action. $MnO_2 + NaCl + 2SO_3 = MnO, SO_3 + NaO, SO_3 + Cl$.

532. Chlorine (from χλωρος, *green*,) is a yellowish green colored gas, which has an astringent taste and a disagreeable odor. It is one of the most suffocating of the gases, exciting spasm and great irritation of the glottis, even when considerably diluted with air. Its density at the usual temperature and pressure is 2.47, which gives 76.59 grains as the weight of 100 cubic inches. Under the pressure of about four atmospheres, it is a limpid liquid of a bright yellow color, which does not freeze at the temperature of zero, and which assumes the gaseous form with the appearance of ebullition when the pressure is removed. This liquid is a non-conductor of electricity.

Cold recently boiled water, at the common pressure, absorbs twice its volume of chlorine, and yields it again when heated. The solution, which is made by transmitting a current of chlorine gas through cold water, has the color, taste, and most of the other properties of the gas itself. When moist chlorine gas is exposed to a cold of 32°, yellow crystals are formed, which consist of 35.42 parts or one equivalent of chlorine, and 90 parts or ten equivalents of water.

533. Chlorine experiences no chemical change from the action of the imponderables. Thus, it is not affected chemically by intense heat, by strong shocks of electricity, or by a powerful galvanic battery. Davy exposed it also to the action of charcoal heated to whiteness by galvanic electricity, without separating oxygen from it, or in any way affecting its nature. It is therefore with propriety considered a simple substance.

Chlorine unites with some substances with evolution of heat and light, and is hence termed a supporter of combustion. If a lighted taper be plunged into chlorine gas, it burns for a short time with a small red flame, and emits a large quantity of smoke. Phosphorus takes fire in it spontaneously, and burns with a pale white light. Several of the metals, such as tin, copper, arsenic, antimony, and zinc, when introduced into chlorine in the state of powder or in fine leaves, are suddenly inflamed. In all these cases the combustible substances unite with chlorine.

534. Chlorine has a very powerful attraction for hydrogen; when mixed together in the diffused light of day, they gradually combine. By exposure to the direct rays of the sun, or by the approach of an ignited body, or the electric spark, they explode. Indeed many of the chemical phenomena to which it gives rise are owing to its affinity for hydrogen. A striking example is its power of decomposing water by the action of light, or at a red heat; and most compound substances, of which hydrogen is an element, are deprived of that principle, and therefore decomposed in like manner. For the same reason, when chlorine, water, and some other body which has a strong affinity for oxygen, are presented to one another, water is usually resolved into its elements, its hydrogen attaching itself to the chlorine, and its oxygen to the other body. Hence it happens that chlorine is, indirectly, one of the most powerful oxydizing agents which we possess.

If a piece of paper be moistened with spirit of turpentine, and suspended by a wire in a bottle of pure, dry chlorine, the turpentine will take fire and burn, the hydrogen combining with the chlorine, and the carbon being precipitated.

535. When any compound of chlorine and an inflammable is exposed to the influence of galvanism, the inflammable body goes over to the negative, and chlorine to the positive pole of the battery. This establishes a close analogy between oxygen and chlorine, both of them being supporters of combustion and both negative electrics.

One of the most important properties of chlorine is its bleaching power. All animal and vegetable colors are speedily removed by it; and when the color is once discharged, it can never be restored. But it cannot bleach unless water is present.

Thus dry litmus paper suffers no change in dry chlorine; but when water is admitted, the color speedily disappears. It is well known also that hydrochloric acid is always generated when chlorine bleaches. From these facts it is inferred that water is decomposed during the process; that its hydrogen unites with chlorine, and that decomposition of the coloring matter is occasioned by the oxygen which is liberated.

Kane, however, contends that the presence of water is not always necessary, if indeed it ever is; but that the chlorine enters into the constitution of the new substance formed by the destruction of the coloring matter, sometimes combining directly with it or replacing hydrogen contained in it, and at others producing a more complex reaction, the different stages of which have not been traced. From its action on organic matter, chlorine is extensively employed as a disinfecting agent, to remove the infectious miasma and offensive effluvia with which the atmospheres of hospitals, sewers, and other places, are often loaded. For this purpose it is desirable that the gas should be evolved slowly but continuously, which is tolerably well accomplished by simply putting some bleaching salt moistened with water in a shallow vessel and placing it in as high a position as possible, in the room to be fumigated. If some sulphuric acid is allowed gradually to fall upon it from a dropping tube, the gas will be evolved more rapidly.

536. Chlorine is in general easily recognized by its color and odor. Chemically it may be detected by its bleaching property, added to the circumstance that a solution of nitrate of oxide of silver occasions in it a dense white precipitate (a compound of chlorine and metallic silver), which becomes dark on exposure to light, is insoluble in acids, and dissolves completely in pure ammonia. When combined with a metal, its solution gives the same kind of precipitate of chloride of silver, but the bleaching properties and smell are absent.

CHLORINE AND OXYGEN.

537. Chlorine and oxygen combine in four different proportions, forming compounds, the leading characteristic of which is derived from the circumstance that chlorine and oxygen, the attraction of which for most elementary substances is so energetic, have but a feeble affinity for each other. These principles, consequently, are never met with in nature in a state of combination with each other. Indeed, they cannot be made to combine directly; and when they do unite, very slight causes effect their separation.

Chemists have not been entirely agreed as to the number of these compounds, but recent experiments have fully established the existence of four as above mentioned, all of which are to be regarded as acids. Their names and constitution are as follows:

	Chlorine.	*Oxygen.*	*Equiv.*	*Symbols.*
Hypochlorous acid	1 eq. +	1 eq.	43.42	ClO
Chlorous acid	1 eq. +	4 eq.	67.42	ClO_4
Chloric acid	1 eq. +	5 eq.	75.42	ClO_5
Perchloric acid	1 eq. +	7 eq.	91.42	ClO_7

538. *Hypochlorous Acid.*—If a current of chlorine is passed through a pure hydrated alkali or alkaline earth, combination takes place, and a bleaching substance is obtained which has generally been considered as a direct compound of chlorine and the alkaline base, but recent experiments show that it is a mixture of a metallic chloride and the hypochlorite of the base used. From this hypochlorite the acid in question is obtained as a transparent liquid of a slightly yellow color.

The pure acid is better prepared by pouring a small quantity of water with half its weight of the red oxide of mercury into a vial of chlorine; the gas, by a little agitation, is entirely absorbed, forming bichloride of mercury and hypochlorous acid, according to the following formula: $HgO^2+4Cl=HgCl^2+2ClO$. The hypochlorous acid being very volatile may be distilled at a low temperature and obtained pure except that it is diluted with water. It has also been obtained in a gaseous state.

This acid possesses a strong and penetrating odor, but different from that of chlorine. It is highly corrosive to the flesh, acting much like nitric acid, but more energetically. In a concentrated state it is very easily decomposed, which effect is produced by the direct rays of the sun, by a slight elevation of temperature, and by a variety of other causes. It is one of the most powerful oxydizing agents known, and possesses strong bleaching properties.

The gas discovered by Davy in 1811, and described by him under the name of *euchlorine*, and by others as *protoxide of chlorine*, is found to be a mixture of chlorine, and chlorous acid, the compound which is next to come before us for examination.

539. *Chlorous Acid.*—This compound was discovered by Davy, in 1815, and has generally been described under the name of peroxide of chlorine, but is now ranked among the acids, as it is proved to form definite compounds with the alkaline bases.

Chlorous acid is formed by the action of sulphuric acid on chlorate of potassa. A quantity of this salt, not exceeding 50 or 60 grains, is reduced to powder, and made into a paste by the addition of strong sulphuric acid. The mixture, which acquires a deep yellow color, is placed in a glass retort, and heated by warm water, the temperature of which is kept under 212°. A bright yellowish-green gas of a richer color than chlorine is disengaged, which has an aromatic odor without any smell of chlorine, and which is absorbed rapidly by water, to which it communicates its tint. This gas is chlorous acid. It may be collected over mercury, or, from its great density, like chlorine (531) in a dry jar.

The chemical changes which take place in the process are explained in the following manner. The sulphuric acid decomposes some of the chlorate of potassa, and sets chloric acid at liberty. The chloric acid, at the moment of separation, resolves itself into chlorous acid and oxygen; the last of which, instead of escaping as free oxygen gas, goes over to the acid of some undecomposed chlorate of potassa, and converts it into perchloric acid. The whole products are bisulphate and perchlorate of potassa and chlorous acid.

Chlorous acid destroys most vegetable blue colors, without previously reddening them. Phosphorus takes fire spontaneously in it, and burns with great brilliancy in the mixture of chlorine and oxygen produced by its decomposition. The combustion of phosphorus may even be effected under water by it. This is done by placing some crystals of chlorate of potassa, and pieces of phosphorus together at the bottom of a tall glass filled with water, and conducting to the mixture some sulphuric acid by means of a glass funnel; as each bubble of chlorous acid is liberated, it produces a rapid and brilliant combustion of the phosphorus. It explodes violently when heated to a temperature of 212°, and emits a strong light.

Chlorous acid unites readily with the alkalies and alkaline earths, by passing a current of the gas through their solutions, which may thus be rendered perfectly neutral.

540. *Chloric Acid.*—If a current of chlorine be transmitted through a strong solution of potassa, a portion of the alkali is decomposed, and chloride of potassium, and hypochlorite of potassa, are formed. If the solution is now heated to the boiling point, this latter salt is decomposed, and after some further complicated changes, there are contained in the solution chlorate of potassa, and chloride of potassium.

When to a dilute solution of chlorate of baryta, weak sulphuric acid, exactly sufficient for combining with baryta, is added, the insoluble sulphate of baryta subsides, and pure chloric acid remains in the liquid.

Chloric acid reddens vegetable blue colors, has a sour taste, and forms neutral salts, called *chlorates*, (formerly *hyperoxymuriates*,) with alkaline bases. It possesses no bleaching properties, a circumstance by which it is distinguished from chlorine. It gives no precipitate in solution of nitrate of oxide of silver, and hence cannot be mistaken for hydrochloric acid. Chloric acid is easily decomposed by deoxydizing agents. Sulphurous acid, for instance, deprives it of oxygen, with formation of sulphuric acid and evolution of chlorine. By the action of hydrosulphuric acid, water is generated, while sulphur and chlorine are set free.

541. *Perchloric Acid.*—The saline matter which remains in the retort after forming chlorous acid (539) is a mixture of perchlorate and bisulphate of potassa; and by washing it with cold water, the bisulphate is dissolved, and the perchlorate is left. Perchloric acid may be prepared from this salt by mixing it in a retort with half its weight of sulphuric acid, diluted with one-third of water, and applying heat to the mixture. At a temperature of about 284° white vapors rise, which condense as a colorless liquid in the receiver. This is a solution of perchloric acid.

CHLORINE AND HYDROGEN.

There is only one compound of hydrogen and chlorine, as follows:

	Chlorine.	*Hydrogen.*	*Equiv.*	*Symbol.*
Hydrochloric acid........	1 eq. +	1 eq......	36.42.....	HCl

542. *Hydrochloric Acid.*—This substance exists naturally as a gas, a solution of which in water has been known from remote ages under the name of *muriatic acid,* or *spirit of salt.*

It was discovered in its pure form of gas by Priestley, in 1772, and may be conveniently prepared by putting an ounce of strong hydrochloric acid solution into a glass flask, and heating it by means of a lamp till the liquid boils, when the gas is freely evolved, and may be collected over mercury. Another method of preparing it is by the action of concentrated sulphuric acid on an equal weight of sea-salt. Brisk effervescence ensues at the moment of making the mixture, and on the application of heat, a large quantity of hydrochloric acid gas is disengaged. In the former process, hydrochloric acid, previously dissolved in water, is simply expelled from the solution by heat. The explanation of the latter process is more complicated. Sea-salt was formerly supposed to be a compound of hydrochloric acid and soda; and on this supposition, the soda was believed merely to quit the hydrochloric and unite with sulphuric acid. But recent researches have proved that it consists of chlorine and sodium combined in the ratio of their equivalents. The nature of its action with sulphuric acid will be understood by comparing the elements concerned in the change before and after it has occurred, by means of the formula: SO_3, $HO+NaCl=NaO$, SO_3+HCl.

Thus it appears that single equivalents of water, sulphuric acid, and chloride of sodium, yield sulphate of soda and hydrochloric acid. The water of the sulphuric acid is essential; so much so, indeed, that chloride of sodium is not decomposed by anhydrous sulphuric acid.

543. Hydrochloric acid may be generated by the direct union of its elements. When equal measures of chlorine and hydrogen are mixed together, and an electric spark is passed through the mixture, instantaneous combination takes place, heat and light are emitted, and hydrochloric acid is generated. A similar effect is produced by flame, by a red-hot body, and by spongy platinum. Light also causes them to unite. A mixture of the two gases may be preserved without change in a dark place; but if exposed to the diffused light of day, gradual combination ensues, which is completed in the course of 24 hours. The direct solar ray, like flame and the electric spark, produces an explosion by a sudden inflammation of the whole mixture; but to insure the success of the experiment, the gases should be very pure, and the chlorine recently prepared over warm water. The glass vial containing the mixed gases, after being filled, should be instantly covered with a black cloth, which an be suddenly removed by a stick or wire after it is placed n the sun's rays.

As equal volumes of the gases combine without any change of volume, the specific gravity of the compound formed must be 1.27, and 100 cubic inches will of course weigh 39.38 grs.

544. Hydrochloric acid gas is colorless, and has a pungent odor and an acid taste. Under a pressure of 40 atmospheres, and at the temperature of 50°, it is liquid. It is quite irrespirable, exciting violent spasm of the glottis; but when diluted with air, it is far less irritating than chlorine. All burning bodies are extinguished by it, nor is the gas itself inflammable.

It is not chemically changed by mere heat, but is readily decomposed by galvanism, hydrogen appearing at the negative, and chlorine at the positive pole. It is also decomposed by ordinary electricity. The decomposition, however, is incomplete; for though one electric spark resolves a portion of the gas into its elements, the next shock in a great measure effects their reunion. It is not affected by oxygen under common circumstances; but if a mixture of oxygen and hydrochloric acid gases is electrified, the oxygen unites with the hydrogen of the acid to form water, and chlorine is set at liberty.

One of the most striking properties of hydrochloric acid gas is its powerful attraction for water. A dense white cloud appears whenever it escapes into the air, owing to its combining with the aqueous vapor of the atmosphere. When a piece of ice is put into a jar full of the gas confined over mercury, the ice liquefies on the instant, and the whole of the gas disappears in the course of a few seconds. On opening a long wide jar of hydrochloric acid gas under water, the absorption of the gas takes place so instantaneously, that the water is forced up into the jar with the same violence as into a vacuum.

The liquid hydrochloric acid of commerce is a solution of this gas in water, which, at the temperature of 40°, will take up 480 times its own volume of it. During the process, the temperature of the water rises, and its volume is considerably increased.

545. The ordinary method of preparing hydrochloric or muriatic acid is to take equal weights of common salt, sulphuric acid, and water; and the acid, diluted with one-third of the water, is poured upon the salt in a retort, the hydrochloric acid gas being made to pass through or into the remaining two-thirds of the water, by which it is entirely absorbed. The specific gravity of the acid thus obtained is 1.17, but by keeping the temperature from rising too high, the acid solution may be made considerably stronger.

Hydrochloric acid of commerce has a yellow color, and is always impure. Its usual impurities are nitric acid, sulphuric acid, and oxide of iron. The presence of these substances may easily be shown by the usual tests.

546. A strong solution of pure hydrochloric acid is a colorless liquid, which emits white vapors when exposed to the air, is intensely sour, reddens litmus paper strongly, and neutralizes

alkalies. It combines with water in every proportion, and causes increase of temperature when mixed with it, though in a much less degree than sulphuric acid. It freezes at —60°, and boils at 110°, or a little higher, giving off pure hydrochloric acid gas in large quantities.

547. Hydrochloric acid is decomposed by substances which yield oxygen readily. Thus several peroxides, such as those of manganese, cobalt, and lead, effect its decomposition. Chloric, iodic, bromic, nitric, and selenic acids act on the same principle. A mixture of nitric and hydrochloric acids, in the ratio of one measure of the former to two of the latter, has long been known under the name of *aqua regia*, or *rex metallorum*, as a solvent for gold and platinum. When these acids are mixed together, the solution instantly becomes yellow; and on heating the mixture, pure chlorine is evolved.

The nitric and hydrochloric acids react upon each other, and chlorine, nitrous acid, and water are produced; $HCl+NO_5=Cl+NO_4+HO$. This decomposition, however, proceeds only so far as to saturate the liquid with chlorine, but if heat is applied to expel the chlorine, or a metal placed in the liquid with which it will unite, new quantities of the acid are decomposed. Nitrohydrochloric acid, therefore, is a source of chlorine in a very concentrated state, and is capable of dissolving several substances which are not attacked by any single acid.

Hydrochloric acid may readily be distinguished by its odor and volatility, and by its giving, with a solution of nitrate of silver, a precipitate of the white chloride of silver, which is blackened by exposure to the light.

This acid is used in the arts with nitric acid, as a solvent for gold and platinum, and in the preparation of hydrochlorate of tin, which is employed as a mordant in coloring. It serves as a solvent for phosphate of lime, and by its action, in a few days, all the solid parts may be removed from bones without destroying their texture, or essentially changing their appearance. It is one of the most important chemical agents employed in the laboratory.

CHLORINE AND NITROGEN.

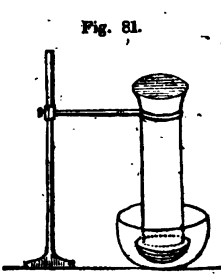
The only known compound of these two substances is the following:

	Chlorine.	*Nitrogen.*	*Equiv.*	*Symbol.*
Quadrochloride of nitrogen	4 eq. +	1 eq.	155.83	NCl_4

548. *Quadrochloride of Nitrogen.*—It seems not entirely settled whether this compound is a ter or a quadro chloride, but probably the latter. Its elements have for each other but a feeble affinity, and do not unite when presented to each other in their gaseous form.

A convenient mode of preparing the quadrochloride of nitrogen is the following. An ounce of ammonia is dissolved in 12 or 16 ounces of hot water; and when the solution has cooled to the temperature of 90°, a glass

Fig. 81.



bottle with a wide mouth, full of chlorine, is inverted in it, as represented in figure 81. The solution gradually absorbs the chlorine, and acquires a yellow color; and in about 20 minutes, globules of a yellow fluid are seen floating like oil upon its surface, which after acquiring the size of a small pea, sink to the bottom of the liquid. The drops of the chloride, as they descend, should be collected in a small saucer of lead, placed for that purpose under the mouth of the bottle.

This substance is one of the most explosive compounds yet known, having been the cause of serious accidents to several who have experimented with it. Its specific gravity is 1.65. It does not congeal in the intense cold produced by a mixture of snow and salt. It may be distilled at 160°; but at a temperature between 200° and 212° it explodes. It appears that its mere contact with some substances of a combustible nature causes detonation even at common temperatures. This result ensues particularly with oils, both volatile and fixed. The products of the explosion are chlorine and nitrogen.

The formation of this compound is never unattended with danger, and should not be attempted but with the utmost caution.

CHLORINE AND CARBON.

There are, it is believed, but three compounds of these elements, the composition of which will appear from the following table:

	Chlorine.	*Carbon.*	*Equiv.*	*Symbols.*
Protochloride of carbon	1 eq. +	1 eq.	41.54	CCl
Dichloride of carbon	1 eq. +	2 eq.	47.66	C_2Cl
Perchloride of carbon	3 eq. +	2 eq.	118.5	C_2Cl_3

The last only of these compounds will be described.

549. *Perchloride of Carbon.*—This compound may be formed by mixing together olefiant gas and chlorine. Combination readily takes place between them, and an oil-like liquid is generated, which consists of chlorine, carbon, and hydrogen. On exposing this liquid, in a vessel full of chlorine gas, to the direct solar rays, the chlorine acts upon and decomposes the liquid, hydrochloric acid is set free, and the carbon, at the moment of separation, unites with the chlorine.

Perchloride of carbon is solid at common temperatures, has an aromatic odor, approaching to that of camphor, is a non-conductor of electricity, and refracts light very powerfully. Its specific gravity is exactly double that of water. It fuses at 320°, and after fusion it is colorless and very transparent. It boils at 360°, and may be distilled without change, assuming a crystaline arrangement as it condenses. It is sparingly soluble in water, but dissolves in alcohol and ether, especially by the aid of heat. It is soluble also in fixed and volatile oils.

Perchloride of carbon burns with a red light when held in the flame of a spirit-lamp, giving out acid vapors and smoke; but the combustion ceases as soon as it is withdrawn. It burns vividly in oxygen gas. Alkalies do not act upon it; nor is it changed by the stronger acids, such as the hydrochloric, nitric, or sulphuric acids, even with the aid of heat. Most of the metals decompose it also at the temperature of ignition, uniting with its chlorine, and causing deposition of charcoal.

CHLORINE AND SULPHUR.

There are, according to Thomson and Kane, two compounds of these substances, as follows:

	Chlorine.	*Sulphur.*	*Equiv.*	*Symbols.*
Chloride of sulphur	1 eq. +	1 eq.	51.52	SCl
Dichloride of sulphur	1 eq. +	2 eq.	67.62	S_2Cl

550. *Dichloride of Sulphur.*—This substance may be prepared by passing a current of chlorine gas through flowers of sulphur gently heated, until nearly all the sulphur disappears. Direct combination ensues, and the product distilled off from uncombined sulphur, is obtained under the form of a liquid which appears red by reflected, and yellowish-green by transmitted light. Its density is 1.69. It is volatile below 200°, boils at 280°, yielding vapor which has a density of 4.70, and condenses again without change in cooling. When exposed to the air it emits acrid fumes, which irritate the eyes powerfully, and has an odor somewhat resembling sea-weed, but much stronger. It acts with energy on water:—mutual decomposition ensues, with formation of hydrochloric and hyposulphurous acids, and deposite of sulphur, by which the water is rendered cloudy.

CHLORINE AND PHOSPHORUS.

Chlorine and phosphorus readily combine, and form the two following compounds, viz.:

	Chlorine.	*Phos.*	*Equiv.*	*Symbols.*
Sesquichloride of phosphorus	3 eq. +	2 eq.	137.66	P_2Cl_3
Perchloride of phosphorus	5 eq. +	2 eq.	208.5	P_2Cl_5

551. *Sesquichloride of Phosphorus.*—Sesquichloride of phosphorus may be prepared by passing vapor of phosphorus over corrosive sublimate contained in a glass tube. It is a clear liquid like water, of specific gravity 1.45; emits acid fumes when exposed to the air, owing to the decomposition of watery vapor; but when pure, it does not redden dry litmus paper. On mixing it with water, mutual decomposition ensues, heat is evolved, and a solution of hydrochloric and phosphorous acids is obtained. Thus P_2Cl_3 and 3HO, give P_2O_3 and 3HCl.

552. *Perchloride of Phosphorus.*—When phosphorus is introduced into a jar of dry chlorine, it inflames, and on the inside of the vessel a white matter collects, which is *perchloride of phosphorus*. It is very volatile, a temperature much below 212° being sufficient to convert it into vapor. Under pressure it may be fused, and it yields transparent prismatic crystals in cooling. In contact with water it is decomposed with the evolution of great heat, producing phosphoric and hydrochloric acids. $P_2Cl_5+5HO=5HCl+P_2O_5$.

CHLORINE, BORON, SILICON, ETC.

553. *Terchloride of boron* (eq. = 117.16, symbol BCl_3,) is formed by exposing recently prepared boron to the action of an atmosphere of chlorine, or by the action of dry chlorine on a mixture of charcoal and boracic acid heated to redness in a porcelain tube. It is a colorless gas, of specific gravity 4.08, soluble in alcohol and water, by the latter of which, however,

it is decomposed, giving rise to the formation of hydrochloric and boracic acids.

554. *Terchloride of silicon* (eq. = 128.76, symbol $SiCl_3$,) may be formed by two methods, either by heating silicon in chlorine, which causes it readily to take fire with the formation of the compound in question, or by passing a current of dry chlorine through a mixture of silicic acid, starch, and oil, heated to redness in a porcelain tube. The mixture of silica, starch, &c., should be heated to redness in a covered crucible before being introduced into the porcelain tube.

Chlorine forms with selenium a compound which resembles the chloride of sulphur.

SECTION XI.

IODINE.

Symbol I; Equivalent 126.3.

555. Iodine was discovered in the year 1812, by M. Courtois, a manufacturer of saltpetre at Paris. In preparing carbonate of soda from the ashes of sea-weeds, he observed that the residual liquor corroded metallic vessels powerfully; and on investigating the cause of the corrosion, he noticed that sulphuric acid threw down a dark-colored matter, which was converted by the application of heat into a beautiful violet vapor. Struck with its appearance, he gave some of the substance to M. Clément, who recognized it as a new body, and in 1813 described some of its leading properties in the Royal Institute of France. Its real nature was soon after determined by Gay-Lussac and Davy, each of whom proved that it is a simple non-metallic substance, exceedingly analogous to chlorine.

556. Iodine is frequently met with in nature, in combination with potassium or sodium. Under this form it occurs in salt and other mineral springs, both in Europe and the United States. It has been detected in the oyster and some other marine molluscous animals, in sponges, and in most kinds of sea-weed. In some of these productions, such as the *Fucus serratus* and *Fucus digitatus*, it exists ready formed, and may be separated by the action of water; but in others it can be detected only after incineration. Marine animals and plants doubtless derive from the sea the iodine which they contain. It is found also in the mineral kingdom, in combination with silver.

557. Iodine may easily be detected in the common sponge in the following manner:—Burn a small piece of the sponge by holding it over a lamp with pincers, in the open air, and lixiviate the ashes with warm water. When this has become cold, introduce a little cold solution of starch, which, however

should be prepared with boiling water, and thoroughly mix it with the liquid. A drop of sulphuric acid let fall into it will at once show the liberation of free iodine, by a purple or blue color given to the liquid at the bottom, where the acid immediately settles.

All the iodine of commerce is procured from the impure carbonate of soda, called *kelp*, which is prepared by incinerating sea-weeds. The kelp is employed by soap-makers for the preparation of carbonate of soda; and the dark residual liquor remaining after that salt has crystalized, contains a considerable quantity of iodine, combined with sodium or potassium. By adding a sufficient quantity of sulphuric acid and peroxide of manganese, hydriodic acid is first generated, and then decomposed. The iodine sublimes when the solution is boiled, and may be collected in cool glass receivers.

A good method of exhibiting the formation of iodine, is to heat in a glass globe, over a lamp or ignited charcoal, a small quantity of sulphuric acid, and throw suddenly into it half a drachm of iodide of potassium. A large quantity of iodine will instantly be set free, and its vapor fill the globe.

558. Iodine, at common temperatures, is a soft, friable, opaque solid, of a bluish-black color and metallic lustre. It occurs usually in crystaline scales, having the appearance of micaceous iron-ore; but it sometimes crystalizes in large rhomboidal plates, the primary form of which is a rhombic octohedron. The crystals are best prepared by exposing to the air a solution of iodine in hydriodic acid. Its specific gravity is 4.95. At 225° it is fused, and enters into ebullition at 347°; but when moisture is present, it is sublimed rapidly even below the degree of boiling water, and suffers a gradual dissipation at low temperatures. Its vapor is of an exceedingly rich violet color, a character to which it owes the name of *iodine*, (from *ιωδης*, *violet-colored.*) This vapor is the heaviest of gaseous bodies, its specific gravity being 8.71, which gives for the weight of 100 cubic inches, 270.1 grains.

Iodine is a non-conductor of electricity, and, like oxygen and chlorine, is a negative electric. It has a very acrid taste, and its odor is very similar to that of chlorine, when much diluted with air.

559. Iodine is very sparingly soluble in water, requiring about 7000 times its weight of that liquid for solution. It communicates, however, even in this minute quantity, a brown tint to it. Alcohol and ether dissolve it freely, and the solution has a deep reddish-brown color.

560. Iodine possesses an extensive range of affinity. It destroys vegetable colors, though in a much less degree than chlorine. It manifests little disposition to combine with metallic oxides; but it has a strong attraction for the pure metals, and for most of the simple non-metallic substances. It is not in-

flammable, but under favorable circumstances may, like chlorine, be made to unite with oxygen.

As iodine cannot be decomposed, it is considered a simple substance.

561. Starch is a most delicate test for free iodine, being changed by it to a beautiful blue color. A distinct blue tinge is said to be communicated to a solution of starch by $\frac{1}{450000}$ of its weight of iodine. The blue color is probably owing to the formation of a definite compound of these substances.

Iodine has not until very recently been used in the arts. It is now made use of in photography, as described above (157).

It acts energetically upon the human system, and is employed in medicine with much success. In large doses it is poisonous.

IODINE AND OXYGEN.

There are, it is believed, four compounds of iodine and oxygen, viz.: oxide of iodine, iodous, iodic, and periodic acids. Of the first two little is known, as they have never been obtained in a separate state. The last two are composed as follows, viz.:

	Iodine.	*Oxygen.*	*Equiv.*	*Symbols.*
Iodic acid	1 eq. +	5 eq.	166.3	IO_5
Periodic acid	1 eq. +	7 eq.	182.3	IO_7

562. *Iodic Acid.*—Iodic acid is formed by the action of iodine upon the euchlorine (538) of Davy, chloride of iodine being generated at the same time. On applying heat, the chloride of iodine is expelled in vapor, while the *iodic* acid remains. It may also be prepared by boiling iodine in fuming nitric acid until it is all dissolved, and then distilling off the excess of acid; and by other means.

This compound is a white semi-transparent solid, which has a strong astringent sour taste, but no odor. Its density is considerable, as it sinks rapidly in sulphuric acid. When heated to the temperature of about 500° it is fused, and at the same time resolved into oxygen and iodine. In a dry air it is unchanged; but in a moist atmosphere it absorbs humidity, forming the hydrated acid, and eventually deliquesces. In water, it is very soluble, and the solution has a distinct acid reaction. It acts powerfully on inflammable substances. With charcoal, sulphur, sugar, and similar combustibles, it forms mixtures which detonate when heated. It enters into combination with metallic oxides, forming salts, which, like the chlorates, yield pure oxygen by heat, and deflagrate when thrown on burning charcoal.

563. *Periodic Acid.*—When a current of chlorine gas is transmitted through a mixture of caustic soda and iodate of sodium in solution, periodate of soda is formed, which subsides by heating, as a sparingly soluble white, pulverulent salt. This may be decomposed by nitrate of silver and the periodic acid obtained, as a white crystaline solid. It is in composition analogous to perchloric acid.

IODINE AND HYDROGEN.

There is but one compound of these substances, viz.:

	Iodine.	*Hydrogen.*	*Equiv.*	*Symbol.*
Hydriodic acid	1 eq. +	1 eq.	127.3	HI

564. *Hydriodic Acid.*—This compound is formed by the direct union of its elements, when a mixture of hydrogen gas and iodine vapor is transmitted through a porcelain tube at a red heat. A more convenient process, and one by which it is obtained in a pure state, is by the action of water on the periodide of phosphorus (567). Any convenient quantity of the iodide is put into a small glass retort, together with a little water, and a gentle heat is applied. Mutual decomposition ensues; the oxygen of the water unites with phosphorus, and its hydrogen with iodine, giving rise to the formation of phosphoric and hydriodic acids, the latter of which passes over in the form of a colorless gas, and may be collected by the method of displacement, as described (531).

Hydriodic acid gas has a very sour taste, reddens vegetable blue colors without destroying them, produces dense white fumes when mixed with atmospheric air, and has an odor similar to that of hydrochloric acid gas. Its specific gravity is 4.39; and therefore 100 cubic inches must weigh 136.13 grains. Like hydrochloric acid gas, it cannot be collected over water; for that liquid dissolves it in large quantity.

When a current of gaseous hydriodic acid is passed through water until it is saturated, a colorless acid solution is formed,—the liquid hydriodic acid. It fumes on exposure to the air, and has a specific gravity of 1.7. It is slowly decomposed by coming in contact with the air.

IODINE AND NITROGEN.

Iodine and nitrogen form only a single compound.

	Iodine.	Nitrogen.	Equiv.	Symbol.
Teriodide of nitrogen	3 eq. +	1 eq.	393.05	NI_3

565. *Teriodide of Nitrogen.*—From the weak affinity that exists between iodine and nitrogen, these substances cannot be made to unite directly. But when iodine is put into a solution of ammonia, the alkali is decomposed; its elements unite with different portions of iodine, and thus cause the formation of hydriodic acid and teriodide of nitrogen. The latter subsides in the form of a dark powder, which is characterized, like quadrochloride of nitrogen, by its explosive property. It often detonates spontaneously as soon as it is dry, and even when moist, by the slightest causes. Heat and light are emitted during the explosion, and iodine and nitrogen are set free, the former of which may be seen at the instant in the form of vapor.

It should be remarked here that recently some have doubted whether this substance is really constituted as above described; but we are not now prepared to discuss the question.

IODINE WITH SULPHUR, PHOSPHORUS, AND CHLORINE.

566 *Iodide of Sulphur* is formed by melting the two substances together in equivalent proportions, and cooling. It is obtained by this means as a steel-gray crystaline mass. Its equivalent is unknown.

567. *Protiodide of Phosphorus* (eq. 142.0, symbol PI,) is formed by mixing together 1 part of phosphorus and 7 or 8 parts of iodine. The preparation requires some care; since phosphorus and iodine act so energetically on each other by mere contact, that the phosphorus is generally inflamed, and a great part of the iodine expelled in the form of vapor. This inconvenience is avoided by putting the phosphorus into a tube, sealed at one end and about twelve inches long, displacing the air by a current of dry carbonic acid gas, then gradually adding the iodine, and promoting the action towards the close by a gentle heat. The materials should be well dried with bibulous paper, and the iodide preserved in a well-stopped dry vessel.

This compound is decomposed by water, with the elements of which it gives hydriodic and phosphorous acids. It is used in the preparation of hydriodic acid (564).

The sesquiodide and periodide of phosphorus may be prepared in precisely the same manner as the protiodide, except that larger proportions of iodine are to be used. They are both solid at ordinary temperatures. They are decomposed by contact with water in the same manner as the protiodide.

Iodine and chlorine form three compounds, ICl, ICl^3, and ICl^5, according to the manner of preparation. The protochloride, which has recently been used in photography (157), is prepared by passing a current of chlorine into water in which iodine is diffused.

SECTION XII.

BROMINE.

Symbol Br; Equivalent 78.4.

568. Bromine was discovered in 1826, by Balard, of Montpelier. The name originally applied to it was *muride*, but the term *brome*, or *bromine*, from βρῶμος, signifying a strong or rank odor, has since been substituted.

Bromine, in its chemical relations, bears a close analogy to chlorine and iodine, and has hitherto been always found in nature associated with the former, and sometimes also with the latter. It exists in sea-water in the form of bromide of sodium, or magnesium. Its relative quantity, however, is very minute;* and even the uncrystalizable residue, called *bittern*, left after chloride of sodium has been separated from sea-water by crystalization, contains it in small proportion. It seems to be an essential ingredient of the saline matter of the ocean, and has been detected in the waters of various mineral springs, in different countries, and in the ashes of some sea-animals.

The usual method of preparing bromine is to transmit a current of chlorine gas through bittern, and then to agitate a portion of sulphuric ether with the liquid. The ether dissolves the whole of the bromine, from which it receives a beautiful hyacinth red tint, and on standing it rises to the surface. When the ethereal solution is agitated with caustic potassa, its color entirely disappears, owing to the formation of bromide of potassium and bromate of potassa, the former of which is obtained in cubic crystals by evaporation. The bromine may then be set free by means of chlorine, and separated by heat.

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* It is said that 100 pounds of sea-water yield only about three and one-fourth grains of bromine.

At common temperatures bromine is a liquid, the color of which is blackish-red, when viewed in mass and by reflected light, but appears hyacinth-red when a thin stratum is interposed between the light and the observer. Its odor, which somewhat resembles that of chlorine, is very disagreeable. Its specific gravity is about 3. Its volatility is considerable; for at common temperatures it emits red-colored vapors, which are very similar in appearance to those of nitrous acid; and at 116.5° it enters into ebullition. By a temperature between zero and —4° it is congealed, and in that state is brittle.

Bromine is a non-conductor of electricity, and undergoes no chemical change whatever from the agency of the imponderables. It may be transmitted through a red-hot glass tube, and be exposed to the agency of galvanism, without evincing the least trace of decomposition. It is therefore considered an elementary substance.

Like oxygen, chlorine, and iodine, it is a negative electric. It is soluble in water, alcohol, and ether, the latter being its best solvent. Its vapor extinguishes a lighted taper; but before going out, it burns for a few seconds with a flame which is green at its base and red at its upper part. Some inflammable substances take fire by contact with bromine, in the same manner as when introduced into an atmosphere of chlorine. It acts with energy on organic matter, such as wood or cork, and corrodes the animal texture; but if applied to the skin for a short time only, it communicates a yellow stain which is less intense than that produced by iodine, and soon disappears. To animal life it is highly destructive, one drop of it placed on the beak of a bird having proved fatal.

Bromine has been by some used in photography (157), in connection with iodine.

With starch it gives a yellow color, which, however, is not intense if the solution is much diluted.

Bromine combines with oxygen and hydrogen, forming acids exceedingly analogous to the compounds formed by the union of chlorine and iodine with the same substances. The same indeed might be said of the compounds it forms with several others of the elementary substances, described in the preceding pages.

SECTION XIII.

FLUORINE.

Symbol F; Equivalent 18.68.

569. This substance, though long known to exist, has not till recently been obtained in an insulated form; nor indeed is any process yet known by which it can be obtained in a state of perfect purity. The difficulty arises from the strength of its affinities, which are such that it is no sooner liberated from its combination with one substance than it enters into union with another, attacking with violence the materials of which the apparatus used may be constructed.

The only substances on which fluorine is incapable of acting are such as are already saturated with it; vessels for preparing it are therefore made of fluor spar, which is a fluoride of calcium. The best method is to fill vessels of this kind with chlorine, and then introduce a little fluoride of mercury; a transfer of elements takes place, chloride of mercury is formed, and fluorine liberated in the form of gas. It is not, however, perfectly pure, but is mixed with chlorine. As thus obtained, it is a colorless gas, possessing an odor somewhat resembling chlorine. Its specific gravity, by calculation, is 1.29. Like oxygen and chlorine, it belongs to the class of negative electrics.

FLUORINE AND HYDROGEN.

Fluorine and hydrogen combine to form the following compound, viz.:

	Fluorine.	*Hydrogen.*	*Equiv.*	*Symbol.*
Hydrofluoric acid	1 eq.	+ 1 eq.	19.68	HF

570. *Hydrofluoric Acid.*—This acid is prepared by acting on the mineral called *fluor spar*, which is a fluoride of calcium, carefully separated from siliceous earth and reduced to fine powder, with twice its weight of concentrated sulphuric acid. The mixture is made in a leaden retort; and on applying heat, an acid and highly corrosive vapor distils over, which must be collected in a receiver of the same metal surrounded with ice. As the materials swell up considerably during the process, owing to a quantity of vapor forcing its way through a viscid mass, the retort should be capacious. At the close of the operation, pure hydrofluoric acid is found in the receiver, and the retort contains dry sulphate of lime. The chemical changes are precisely the same as in the formation of hydrochloric acid gas (542), fluorine being substituted for chlorine, and calcium for sodium. That is, SO_3, HO, and CaF, give CaO, SO_3, and HF. If the sulphuric acid is of sufficient strength, all

its water is decomposed, and the resulting hydrofluoric acid is anhydrous.

Hydrofluoric acid, at the temperature of 32°, is a colorless liquid, and remains in that state at 59° if preserved in well-stopped bottles; but when exposed to the air, it flies off in dense white fumes, which consist of the acid vapor combined with the moisture of the atmosphere. Its specific gravity is 1.06; but its density may be increased to 1.25 by gradual additions of water. Its affinity for this liquid far exceeds that of the strongest sulphuric acid, and the combination is accompanied with a hissing noise, as when red-hot iron is quenched by immersion in water.

The vapor of hydrofluoric acid is much more pungent than chlorine or any of the irritating gases. Of all known substances, it is the most destructive to animal matter. When a drop of the concentrated acid of the size of a pin's head comes in contact with the skin, instantaneous disorganization ensues, and deep ulceration of a malignant character is produced. On this account the greatest care is requisite in its preparation.

571. This acid, when concentrated, acts energetically on glass. Its transparency is instantly destroyed, heat is evolved, and the acid boils, and in a short time entirely disappears. A colorless gas, commonly known by the name of *fluosilicic acid gas*, is the sole product. This compound is always formed when hydrofluoric acid comes in contact with a siliceous substance. For this reason it cannot be preserved in glass; but must be prepared and kept in metallic vessels. Those of lead, from their cheapness, are often used; but vessels of silver or platinum are preferable. In consequence of its powerful affinity for siliceous matter, hydrofluoric acid may be employed for etching on glass; and when used with this intention, it should be diluted with three or four times its weight of water.

572. Etching upon glass by the liquid is accomplished in the following manner: The plate of glass is first covered with wax of uniform thickness, and then, with a needle or graver, the design is traced on it, taking care to cut quite through to the surface of the glass. A rim of wax is then formed around the edge of the plate, and the liquid poured upon it and allowed to remain a sufficient time to corrode the glass considerably, where it comes in contact with it. It is then poured off, and the wax removed.

Etching may be done equally well by exposing the plate properly prepared as above, directly to the action of the hydrofluoric acid vapor as it is formed (580). For this purpose a shallow leaden vessel is to be prepared, of sufficient size just to receive the plate at the top; and the powdered fluor spar and sulphuric acid being placed at the bottom, the vapor, as it rises by the application of heat, attacks the glass, by separating the silica, and producing fluosilicic acid. When the corrosion is sufficient, the plate is removed and the wax cleared off as before.

573. Hydrofluoric acid has all the usual characters of a powerful acid. It has a strong sour taste, reddens litmus paper,

and neutralizes alkalies, either forming salts termed *hydrofluates*, or most generally giving rise to metallic fluorides. All these compounds are decomposed by strong sulphuric acid with the aid of heat, and the hydrofluoric acid while escaping may be detected by its action on glass.

This acid acts violently on some of the metals, especially on the bases of the alkalies. Thus, when potassium is brought in contact with the concentrated acid, an explosion, attended with heat and light, ensues; hydrogen gas is disengaged, and a white compound, fluoride of potassium, is generated. It is a solvent for some elementary principles, which resist the action even of nitro-hydrochloric acid. Thus it dissolves silicon, zirconium, and columbium, with evolution of hydrogen gas; and when mixed with nitric acid, it proves a solvent for silicon which has been condensed by heat (523), and for titanium. Nitro-hydrofluoric acid, however, is incapable of dissolving gold and platinum. Several oxydized bodies, which are not attacked by sulphuric, nitric, or hydrochloric acid, are readily dissolved by hydrofluoric acid.

FLUORINE AND BORON.

The only compound of fluorine and boron known is the following, viz.:

	Fluorine.	*Boron.*	*Equiv.*	*Symbol.*
Fluoboric Acid	3 eq. +	1 eq.	66.98	BF_3

574. *Fluoboric Acid.*—The chief difficulty in determining the nature of hydrofluoric acid arises from the water of the sulphuric acid which is employed in its preparation. To avoid this source of uncertainty, Gay-Lussac and Thenard made a mixture of vitrified boracic acid and fluor spar, and exposed it in a leaden retort to heat, under the expectation that, as no water was present, anhydrous fluoric acid would be obtained. In this, however, they were disappointed; but a new gas came over, to which they applied the term of *fluoboric acid gas.*

In the decomposition of fluor spar by vitrified boracic acid, the former and part of the latter undergo an interchange of elements. The fluorine uniting with boron, gives rise to fluoboric acid gas; and by the union of calcium and oxygen, lime is generated, which combines with boracic acid, and is left in the retort as borate of lime. Fluoboric acid gas, therefore, is composed of boron and fluorine.

Fluoboric acid gas is colorless, has a penetrating pungent odor, and extinguishes flame on the instant. Its specific gravity is 2.36. It reddens litmus paper as powerfully as sulphuric acid, and forms salts with alkalies, which are called *fluoborates.* It has a singularly great affinity for water. When mixed with air or any gas which contains watery vapor, a dense white cloud, a combination of water and fluoboric acid appears, thus affording an extremely delicate test of the presence of moisture in gases. Water acts powerfully on this gas, absorbing 700 times its volume, during which the water increases in temperature and volume. The solution is limpid, fuming, and very caustic. On the application of heat, part of the gas is disengaged; but afterwards the whole solution is distilled.

Fluoboric acid gas does not act on glass, but attacks animal and vegetable matter with energy, converting them like sulphuric acid into a carbonaceous substance. This action is most probably owing to its affinity for water.

When potassium is heated in fluoboric acid gas, the metal takes fire, and a chocolate-colored solid, wholly devoid of metallic lustre, is formed. This substance is a mixture of boron and fluoride of potassium, from which the latter is dissolved by water, and the boron is left in a solid state.

The composition of this acid has not been determined by direct experiment, but there are satisfactory reasons for believing it to be as stated in the above table.

FLUORINE AND SILICON.

There is but one compound of fluorine and silicon, called fluosilicic acid, or sometimes terfluoride of silicon.

	Fluorine.		*Silicon.*	*Equiv.*	*Symbol.*
Terfluoride of silicon............	3 eq.	+	1 eq......	78.5.....	SiF_3

575. *Terfluoride of Silicon, or Fluosilicic Acid.*—This substance is formed whenever hydrofluoric and silicic acids come in contact. The most convenient method of procuring it is to mix in a retort one part of pulverized fluor spar with its own weight of sand or pounded glass, and two parts of strong sulphuric acid. On applying a gentle heat, fluosilicic acid gas is disengaged with effervescence, and may be collected over mercury.

It is a colorless gas which extinguishes flame, destroys animal life, and irritates powerfully the respiratory organs. When mixed with the air, it forms a white cloud, by combining with watery vapor. Its specific gravity is 3.61, and 100 cubic inches weigh 111.95 grains.

It has a strong affinity for water, which absorbs it rapidly, but causing its decomposition with formation of hydrate of silica at the same time.

CHAPTER III.

METALLIC ELEMENTS.

SECTION I.

GENERAL PROPERTIES.

576. **Metals** are distinguished from other substances by the following properties. They are all conductors of electricity and heat. When the compounds which they form with oxygen, chlorine, iodine, sulphur, and similar substances, are submitted to the action of galvanism, the metals always appear at the negative side of the battery, and are hence said to be positive electrics. They are quite opaque, refusing a passage to light though reduced to very thin leaves. They are in general good reflectors of light, and possess a peculiar lustre, which is termed the metallic lustre. Every substance in which these characters reside may be regarded as a metal.

577. The number of metals, the existence of which is admitted by chemists, amounts to forty-two. The following table contains the names of those that have been procured in a state of purity, together with the date at which they were discovered, and the names of the chemists by whom the discovery was made. There are one or two others of which little is known.

TABLE OF THE DISCOVERY OF METALS.

Names of Metals.	*Authors of the Discovery.*	*Dates of the Discovery.*
Gold	Known to the Ancients.	
Silver		
Iron		
Copper		
Mercury		
Lead		
Tin		
Antimony	Described by Basil Valentine	1490.
Bismuth	Described by Agricola	1530.
Zinc	First mentioned by Paracelsus	16th century.
Arsenic	Brandt	1733.
Cobalt		
Platinum	Wood, assay-master, Jamaica	1741.
Nickel	Cronstedt	1751.
Manganese	Gahn and Scheele	1774.
Tungsten	D'Elhuyart	1781.
Tellurium	Müller	1782.
Molybdenum	Hielm	1782
Uranium	Klaproth	1789.
Titanium	Gregor	1791.
Chromium	Vauquelin	1797.
Columbium	Hatchett	1802.
Palladium	Wollaston	1803.
Rhodium		
Iridium	Decotils and Smithson Tennant	1803.
Osmium	Smithson Tennant	1803.
Cerium	Hisinger and Berzelius	1804.
Potassium	Davy	1807.
Sodium		
Barium		
Strontium		
Calcium		
Cadmium	Stromeyer	1818.
Lithium	Arfwedson	1818.
Zirconium	Berzelius	1824.
Aluminum	Wöhler	1828.
Glucinum		
Yttrium		
Thorium	Berzelius	1829.
Magnesium	Bussy	1829.
Vanadium	Seftström	1830.
Lanthanum	Mosander	1839.

578. Most of the metals are remarkable for their great specific gravity; several of them being more than 10 times as heavy as an equal bulk of water; and one of them, platinum, which is the densest body known, about 21 times as heavy as water. Great density was once supposed to be an essential characteristic of metals; but the discovery of potassium and sodium, which are so light as to float on the surface of water, has shown that this supposition is erroneous. Some metals experience an increase of density to a certain extent when hammered, their particles being permanently approximated by the operation. On this account, the density of some of the metals varies; but the numbers in the following table express their specific gravities before they are hammered.

Table of the Specific Gravity of Metals at 60°, *compared with Water as Unity.*

Platinum	20.98	Cobalt	8.538
Gold	19.257	Nickel	8.279
Tungsten	17.6	Manganese	8.013
Mercury	13.568	Iron	7.788
Palladium	11.5	Tin	7.291
Lead	11.352	Zinc	6.86
Silver	10.474	Antimony	6.702
Bismuth	9.822	Tellurium	6.14
Uranium	9.000	Arsenic	5.884
Copper	8.9	Titanium	5.3
Cadmium	8.604	Sodium	0.972
Molybdenum	8.6	Potassium	0.865

579. Some metals possess the property of *malleability*, that is, admit of being beaten into thin plates or leaves by hammering. The malleable metals are gold, silver, copper, tin, platinum, palladium, cadmium, lead, zinc, iron, nickel, potassium, sodium, and frozen mercury. The other metals are either malleable in a very small degree only, or, like antimony, arsenic, and bismuth, are actually brittle. Gold surpasses all metals in malleability; one grain of it may be extended so as to cover about 52 square inches of surface, and to have a thickness not exceeding $\frac{1}{282020}$ of an inch.

Nearly all malleable metals may be drawn out into wires, a property which is expressed by the term *ductility*. The only metals which are remarkable in this respect are gold, silver, platinum, iron, and copper. Wollaston devised a method by which gold wire may be obtained so fine that its diameter should be only $\frac{1}{5000}$ of an inch, and that 550 feet of it are required to weigh one grain. He obtained a platinum wire so small, that its diameter did not exceed $\frac{1}{3000}$ of an inch. It is singular that the ductility and malleability of the same metal are not always in proportion to each other. Iron, for example, cannot be made into fine leaves, but it may be drawn into very small wires.

Both the malleability and ductility of several of the metals vary with the temperature. Thus iron, though partially malleable and ductile at the ordinary temperature of the atmosphere, is much more so at a red heat; and zinc is very malleable from 212° to 350°, but loses this property if cooled down to 32°, or heated to 600°. At the latter temperature, it is decidedly brittle.

The tenacity of metals is measured by ascertaining the greatest weight which a wire of a certain thickness can support without breaking. According to the experiments of Guyton-Morveau, whose results are comprised in the following table, iron, in point of tenacity, surpasses all other metals.

The diameter of each wire was 0.787 of a line.

	Pounds.		*Pounds.*
Iron wire supports	549.25	Gold	150.753
Copper	302.278	Zinc	109.54
Platinum	274.32	Tin	34.63
Silver	187.137	Lead	27.621

580. The metals differ much in hardness also, but we are not able to compare them with reference to this property with mathematical precision. In the list of hard metals may be placed titanium, manganese, iron, nickel, copper, zinc, and palladium. Gold, silver, and platinum are softer than these; lead is softer still, and potassium and sodium yield to the pressure of the fingers. The properties of elasticity and sonorousness are allied to that of hardness. Iron and copper are in these respects the most conspicuous.

When a metal has been hammered or drawn out into wire, its hardness as well as density is increased; and it becomes less malleable. This property, however, is restored by *annealing* it, which consists in heating it to redness and then cooling it slowly. But the tenacity is often very much diminished by the process, sometimes even more than one-half. This is supposed to be occasioned by a kind of partial crystalization that takes place.

581. Many of the metals have a distinctly crystaline texture Iron, for example, is fibrous; and zinc, bismuth, and antimony are lamellated. Metals are sometimes obtained also in crystals; and most of them, in crystalizing, assume the figure of the cube, the regular octohedron, or some form allied to it. Gold, silver, and copper occur naturally in crystals, while others crystalize when they pass gradually from the liquid to the solid condition. Crystals are most readily procured from those metals which fuse at a low temperature; and bismuth, from conducting heat less perfectly than other metals, and therefore, cooling more slowly, is best fitted for the purpose.

The point of fusion in the different metals varies exceedingly. Mercury fuses at —39°, potassium at 136°, tin at 442°, zinc at

773°, gold at 2016°, while platinum and some others require the intense heat of the compound blowpipe.

Some of them, as arsenic, cadmium, mercury, zinc, &c., are volatilized by heat without difficulty, but others are fixed in the most intense heat that can be produced.

The metals are universally considered as elementary bodies.

They have an extensive range of affinity, and on this account few of them are found in the earth *native*, that is, in an uncombined form. They commonly occur in combination with other bodies, especially with oxygen and sulphur, in which state they are said to be *mineralized*. It is a singular fact in the chemical history of the metals, that they are little disposed to combine in the metallic state with compound bodies, such as an oxide or an acid. They unite readily, on the contrary, with elementary substances.

They often combine with each other, forming compounds called *alloys*, which will be described in their proper places. They possess all the characteristic physical properties of the pure metals, and many of them are of great service in the arts. Generally, alloys are more fusible and more oxydable than their constituents separately. Their malleability and ductility usually are much less, and their hardness greater, than those of the metals of which they are composed.

Compounds of mercury with other metals are called *amalgams*.

Metals are of a combustible nature; that is, they are not only susceptible of slow oxydation, but, under favorable circumstances, they unite rapidly with oxygen, giving rise to all the phenomena of real combustion. Zinc burns with a brilliant flame when heated to full redness in the open air; iron emits vivid scintillations on being inflamed in an atmosphere of oxygen gas; and the least oxydable metals, such as gold and platinum, scintillate in a similar manner when heated by the oxy-hydrogen blowpipe.

582. The product either of the slow or rapid oxydation of a metal, when heated in the air, has an earthy aspect, and was called a *calx* by the older chemists, the process of forming it being expressed by the term *calcination*. Another method of oxydizing metals is by *deflagration;* that is, by mixing them with nitrate or chlorate of potassa, and projecting the mixture into a red-hot crucible. Most metals may be oxydized by digestion in nitric acid; and nitro-hydrochloric acid is an oxydizing agent of still greater power.

583. Metals differ remarkably in their relative forces of attraction for oxygen. Potassium and sodium, for example, are oxydized by mere exposure to the air; and they decompose water, at all temperatures, the instant they come in contact with it. Iron and copper may be preserved in dry air without change, nor can they decompose water at common tempera-

tures; but they are both slowly oxydized by exposure to a moist atmosphere, and combine rapidly with oxygen when heated to redness in the open air.

Mercury is less inclined than either of these to combine with oxygen, and gold will bear the most intense heat of our furnaces without oxydation.

Some of the metals unite with oxygen in one proportion only, but most of them have two or three degrees of oxydation. The resulting compounds are either oxides or acids. With the exception of arsenic, the metals all produce oxides by combination with oxygen; and many of them which produce oxides by combining with one proportion of oxygen, form acids when united with two or more proportions. This occurs in the case of chromium, tungsten, molybdenum, vanadium, and several others.

The metallic oxides sometimes combine with each other, and form definite compounds. The most abundant ore of chromium, usually called chromate of iron, is an instance of this kind.

The metals are separated from the substances with which they are found naturally combined, by a variety of processes, which constitute the branch of chemistry denominated *metallurgy.*

584. Metallic oxides suffer *reduction*, or may be reduced to the metallic state in several ways:

1. By mere heat. By this method the oxides of gold, silver, mercury, and platinum may be decomposed.

2. By the united agency of heat and combustible matter. Thus, by transmitting a current of hydrogen gas over the oxides of copper or iron heated to redness in a tube of porcelain, water is generated, and the metals are obtained in a pure form. Carbonaceous matters are likewise used for the purpose with great success. Potassa and soda, for example, may be decomposed by exposing them to a white heat, after being intimately mixed with charcoal in fine powder. A similar process is employed in metallurgy for extracting metals from their ores, the inflammable materials being wood, charcoal, coke, or coal. In the more delicate operation of the laboratory, charcoal and *black flux** are employed.

3. By the galvanic battery. This is a still more powerful agent than the preceding; since some oxides, such as baryta and strontia, which resist the united influences of heat and charcoal, are reduced by the agency of galvanism.

4. By the action of deoxydizing agents on metallic solutions. Phosphorous acid, for example, when added to a liquid containing oxide of mercury, deprives the oxide of its oxygen,

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* *Black flux* is prepared by deflagrating nitre with twice its weight of cream of tartar. When equal weights are used, it constitutes *white flux.*

metallic mercury subsides, and phosphoric acid is generated.* In like manner one metal may be precipitated by another; provided the affinity of the latter for oxygen exceeds that of the former. Thus, when mercury is added to a solution of nitrate of the oxide of silver, metallic silver is thrown down, and oxide of mercury is dissolved by the nitric acid. On placing metallic copper in the liquid, pure mercury subsides, and a nitrate of the oxide of copper is formed; and from this solution metallic copper may be precipitated by means of iron.

585. Several of the metals, by combining with oxygen, form both oxides and acids, as chromium, tungsten, and molybdenum; but the most form only oxides. One of them, arsenic, united with oxygen, forms only acids. In those instances in which metals form with oxygen both oxides and acids, the latter always contain the most oxygen.

Many of the metallic oxides have the property of combining with acids. In some instances all the oxides of a metal are capable of forming salts with acids, as is exemplified by the oxides of iron; but, generally, the protoxide is the sole *alkaline* or *salifiable base*. Most of the metallic oxides are insoluble in water; but all those that are soluble have the property of giving a brown stain to yellow turmeric paper, and of restoring the blue color of reddened litmus.

586. Chlorine has a powerful affinity for metallic substances. It combines readily with most metals at common temperatures, and the action is in many instances so violent as to be accompanied with the evolution of light. For example, when powdered zinc, arsenic, or antimony, is thrown into a jar of chlorine gas, the metal is instantly inflamed: The attraction of chlorine for metals even surpasses that of oxygen. Thus, when chlorine is brought into contact at a red heat with pure lime, magnesia, baryta, strontia, potassa, or soda, oxygen is emitted, and a chloride of the metal is generated, the elements of which are so strongly united that no temperature hitherto tried can separate them. All other metallic oxides are, with few exceptions, acted on in the same manner by chlorine, and in some cases the change takes place below the temperature of ignition.

Most of the metallic chlorides are solid at common temperatures. They are fusible by heat, assume a crystaline texture in cooling, and under favorable circumstances, crystalize with regularity. Several of them, such as the chlorides of tin, arsenic, antimony, and mercury, are volatile, and may be sublimed without change. They are for the most part colorless, do not possess the metallic lustre, and have the aspect of a salt. Two of the chlorides are insoluble in water, namely, chloride of silver and protochloride of mercury; several, such as the chlorides of antimony, arsenic, and titanium, are decomposed by that liquid; but most of them are more or less soluble.

Some of the metallic chlorides are decomposable by heat, especially those of gold and platinum. Most of them are decomposed by concentrated sulphuric acid, or by hydrogen at a red heat.

Metallic chlorides may in most cases be formed by the direct action of chlorine on the pure metals, or by dissolving them or their oxides in hydrochloric acid, and evaporating to dryness. All chlorides, when in solution, may be recognized by yielding, with nitrate of silver, a white precipitate, which is chloride of silver. It shortly turns black by exposure to light.

587. When a metallic chloride is dissolved in water, two different views may be taken of the changes that occur. First, the chloride may be dissolved as such in the water, and a real solution of the chloride in water be formed. When the water is evaporated, the chloride will again be deposited, in some cases in a crystaline form.

Secondly, the chloride, on coming in contact with the water, may be decomposed at the same time with a portion of the water; the chlorine of the chloride mixing with the hydrogen of the water to form hydrochloric acid, the metallic base of the chloride being at the same time oxydized by the oxygen of the water. The solution then will be a solution of the hydrochlorate of the *base* of the chloride, instead of the chloride itself. The chloride of potassium on this theory, therefore, on being dissolved in water, is converted into hydrochlorate of potassa; and when evaporated to dryness, the elements existing in the salt reunite as they were before solution was attempted, and crystals of chloride of potassium are deposited.

Of those compounds which, on crystalizing, retain water or its elements in combination, two opinions may be formed. Thus, crystalized hydrochlorate of baryta, which consists of one equivalent of chlorine, one of barium, two of oxygen, and two of hydrogen, may be regarded as a compound either of hydrochlorate of baryta, with one equivalent of water of crystallization, or of chloride of barium, with two equivalents of water. When exposed to heat, two equivalents of water are expelled, and chloride of barium is left.

The probability is that in some cases metallic chlorides are dissolved as such in water, according to the first of the above hypotheses, and that in other cases they are converted at the moment of solution into hydrochlorates, as explained by the second. It is usual, however, to speak of them all as being dissolved as such in water, to avoid the recurrence of two-fold explanations.

The remarks made in this place concerning the metallic chlorides, will apply in the same manner to the iodides, bromides, and fluorides.

588. Iodine has a strong attraction for metals; and most of the compounds which it forms with them sustain a red heat in

close vessels without decomposition. But in the degree of its affinity for metallic substances it is inferior to chlorine and oxygen. If the vapor of iodine is brought in contact with potassa, soda, protoxide of lead, or oxide of bismuth, heated to redness, oxygen gas is evolved, and the metals of these oxides will unite with iodine. But iodine, so far as is known, cannot separate oxygen from any other metal; nay, all the iodides, except those just mentioned, are decomposed by exposure to oxygen gas at the temperature of ignition. All the iodides are decomposed by chlorine, bromine, and concentrated sulphuric and nitric acids; and the iodine which is set free may be recognized either by the color of its vapor, or by its action on starch (561). The metallic iodides are generated under circumstances analogous to those above mentioned (586) for procuring the chlorides.

The action of iodine on metallic oxides, when dissolved or suspended in water, is precisely analogous to that of chlorine. On adding iodine to a solution of the pure alkalies or alkaline earths, an iodide and iodate are generated (540).

Bromine, in its affinity for metallic substances, is intermediate between chlorine and iodine; for while chlorine disengages bromine from its combination with metals, metallic iodides are decomposed by bromine.

589. As fluorine has but recently been obtained in an insulated form, and then only in mixture with chlorine, the nature of its action on the metals is not well known; but the chief difficulty of procuring it in a separate state (569) appears to arise from its extremely powerful affinity for metallic substances, in consequence of which, at the moment of becoming free, it attacks the vessels and instruments employed in its preparation. The fluorides are, without exception, decomposed by concentrated sulphuric acid, with the aid of heat.

590. Sulphur, like the preceding elementary substances, has a strong tendency to unite with metals, and the combination may be effected in several ways:

1. By heating the metal directly with sulphur. The metal, in the form of powder or filings, is mixed with a due proportion of sulphur, and the mixture heated in an earthen crucible, which is covered, to prevent the access of air; or if the metal can sustain a red heat without fusing, the vapor of sulphur may be passed over it while heated to redness in a tube of porcelain. Sometimes it is sufficient to hold the substance in a jet of vapor of sulphur, which, of course, must be highly heated. A real combustion, in perfect accordance with the definition of this term, given above (133 and 373), takes place, in which the vapor of sulphur serves as the supporter.

2. By igniting a mixture of a metallic oxide and sulphur.

3. By depriving the sulphate of an oxide, of its oxygen, by

means of heat and combustible matter. Charcoal or hydrogen gas may be employed for the purpose.

4. By the action of hydrosulphuric acid, or a soluble sulphuret upon the metallic salts.

The sulphurets are opaque, brittle solids, many of which, such as the sulphurets of lead, antimony, and iron, have a metallic lustre. They are all fusible by heat, and commonly assume a crystaline texture in cooling. Most of them are fixed in the fire; but the sulphurets of mercury and arsenic are remarkable for their volatility. All the sulphurets, excepting those of the first class of metals, are insoluble in water.

Most of the protosulphurets support an intense heat without decomposition; but, in general, those which contain more than one equivalent of sulphur, lose part of it when strongly heated. They are all decomposed, without exception, by exposure to the combined agency of air or oxygen gas and heat; and the products depend entirely on the degree of heat and the nature of the metal. Sometimes the sulphuret is more or less converted into the sulphate of an oxide, and at others the sulphur is evolved under the form of sulphurous acid, and a metallic oxide, or even the pure metal, remains.

591. An opinion formerly prevailed that many of the metallic sulphurets are compounds of sulphur and a metallic oxide. For instance, sulphuret of potassa and sulphuret of soda, as they were called, were supposed to be, as the names indicate, compounds of sulphur with these alkalies. But it has been shown by Berzelius and others, that the sulphur, instead of combining with the alkali, unites with its metallic base. The compounds mentioned above, therefore, are to be considered as sulphuret of potassium, and sulphuret of sodium. By the action of sulphur upon a metallic oxide, in those cases when combination takes place, a part of the oxide is decomposed, the oxygen of which combines with a portion of the sulphur, forming sulphuric acid, the metal itself immediately combining with another portion of the sulphur to form a metallic sulphuret. The sulphuric acid produced in this manner unites immediately with a part of the oxide, so that the result will be a mixture of sulphuret of the metal itself, and sulphate of its oxide.

So also when carbon or a current of hydrogen is brought in contact with a metallic sulphate intensely heated, the sulphuric acid and the metallic oxide are both deoxydized, and a metallic sulphuret obtained. It is therefore rendered very certain that no definite compound of sulphur and a metallic oxide exists.

Many of the metallic sulphurets in some respects much resemble the oxides. Some of them are acids and others bases, which unite to form an important class of salts, called *sulphur salts*, as will hereafter be shown.

Several of the metallic sulphurets occur abundantly in nature. Those that are most frequently met with are the sulphurets of lead, antimony, copper, iron, zinc, molybdenum, and silver.

592. The metallic seleniurets have so close a resemblance in their chemical relations to the sulphurets, that it is unnecessary to give a separate description of them. They may be prepared either by bringing selenium in

contact with the metals at a high temperature, or by the action of hydroselenic acid on metallic solutions.

Chemists are acquainted with several metallic phosphurets; and it is probable that phosphorus, like sulphur, is capable of uniting with all the metals, but the subject has received comparatively little attention.

The metallic phosphurets may be prepared in several ways; as, by bringing phosphorus in contact with the metals at a high temperature, by igniting them in contact with phosphorus, or by transmitting a current of phosphuretted hydrogen gas over metallic oxides heated to redness in a porcelain tube.

Phosphorus is said to unite with metallic oxides. For example, phosphuret of lime is said to be formed by conducting the vapor of phosphorus over that earth at a low red heat; but it is probable that in this instance, as with a mixture of sulphur and an alkali, part of the metallic oxide is decomposed, and that the product contains phosphuret of calcium and phosphate of lime.

The only metallic carburets of importance are those of iron, which will be described in the section on that metal.

Some of the metals, as tellurium, arsenic, and antimony, combine with hydrogen and form gaseous compounds, which in their constitution and properties closely resemble the sulphurets (496) and phosphurets (515) of hydrogen. In these compounds the hydrogen is the electro-positive element, the metal playing the part of the sulphur or phosphorus.

593. The discoveries of modern chemistry have materially added to the number of the metals, especially by associating with them a class of bodies which was formerly believed to be of a nature entirely different. The metallic bases of the alkalies and earths, previous to the year 1807, were altogether unknown; and before that date, the list of metals, with few exceptions, included those only which are commonly employed in the arts, and which are hence often called the common metals. In consequence of this increase in number, it is found convenient, for the purpose of description, to arrange them in separate groups; and they are therefore divided into two classes, and each class into three orders.

CLASS I. Metals which, by oxydation, yield alkalies and earths.

CLASS II. Metals, the oxides of which are not alkalies or earths.

CLASS I. This class includes twelve metals, which may properly be arranged in three orders.

Order 1. Metallic bases of the alkalies. They are three in number: namely,

Potassium, Sodium, Lithium,

These metals have such a powerful attraction for oxygen, that they decompose cold water, and even ice at the moment of contact, and are oxydized with disengagement of hydrogen gas. The resulting oxides are distinguished by their causticity and solubility in water, and by possessing alkaline properties in an eminent degree. They are called *alkalies*, and their metallic bases are sometimes termed *alkaline* or *alkaligenous* metals.

Order 2. Metallic bases of the alkaline earths. These are four in number; namely,

Barium,
Strontium,
Calcium,
Magnesium,

These metals, excepting magnesium, also decompose water rapidly at common temperatures. The resulting oxides are called *alkaline earths;* because, while in their appearance they resemble the earths, they are similar to the alkalies, in having a strong alkaline reaction with test paper, and in neutralizing acids. The three first are strongly caustic, and baryta and strontia are soluble in water to a considerable extent.

Order 3. Metallic bases of the earths. These are five in number; namely,

Aluminum,
Yttrium,
Zirconium,
Glucinum,
Thorium.

The oxides of these metals are well known as the pure earths. They are white and of an earthy appearance, in their ordinary state are quite insoluble in water, and do not affect the color of turmeric or litmus paper. As salifiable bases they are inferior to the alkaline earths.

CLASS II. The number of the metals included in this class amounts to thirty. The protoxides of most of them, and sometimes the sesqui and binoxides, act as salifiable bases in uniting with acids, and forming salts; but in this respect they are much inferior to the alkalies and alkaline earths, by which they may be separated from their combinations. Several of these metals are capable of forming with oxygen compounds, which possess the character of acids. The metals in which this property has been noticed are manganese, arsenic, chromium, vanadium, molybdenum, tungsten, columbium, antimony, titanium, tellurium, gold, osmium, and tin.

The metals belonging to the second class may be conveniently arranged in the three following orders:—

Order 1. Metals which decompose water at a red heat. They are seven in number; namely,

Manganese,
Tin,
Cadmium,
Nickel,
Cobalt,
Zinc,
Iron,

Order 2. Metals which do not decompose water at any temperature, and the oxides of which are not reduced to the metallic state by the sole action of heat. Of these there are fifteen; namely,

Arsenic,
Chromium,
Vanadium,
Molybdenum,
Tungsten,
Columbium,
Antimony,
Uranium,
Cerium,
Lanthanum,
Bismuth,
Titanium,
Tellurium,
Copper,
Lead.

Order 3. Metals, the oxides of which are decomposed by a red heat. These are,

Mercury,
Silver,
Gold,
Platinum,
Palladium,
Rhodium,
Osmium,
Iridium.

SECTION II.

METALLIC BASES OF THE ALKALIES.

POTASSIUM.

Symbol K; Equivalent 39.15.

594. **Potassium**, or kalium, was discovered by Davy, in the year 1807, in the following manner: Hydrate of potassa, slightly moistened, for the purpose of increasing its conducting power, was made to communicate with the opposite poles of a powerful galvanic battery, formed by uniting several smaller batteries; when the oxygen both of the water and the potassa passed over to the positive pole; while the hydrogen of the former, and the potassium of the latter, made their appearance at the negative pole. By this process, potassium is obtained in small quantity only; but Gay-Lussac and Thenard invented a method by which a more abundant supply may be procured. Their process consists in bringing fused hydrate of potassa in contact with turnings of iron heated to whiteness in a gun-barrel. The iron, under these circumstances, deprives the water and potassa of oxygen, hydrogen gas combined with a little potassium is evolved, and pure potassium sublimes, and may be collected in a cool part of the apparatus.

Potassium may also be prepared, by mixing dry carbonate of potassa with half its weight of powdered charcoal, and exposing the mixture, contained in a gun-barrel or spheroidal iron bottle, to a strong heat.

A further improvement consists in mixing the fused carbonate of potassa intimately with a mixture of iron filings and charcoal powder, and exposing to a high temperature. An intimate mixture of carbon with the carbonate of potassa is obtained by heating tartrate of potassa to redness.

595. Potassium is solid at the ordinary temperature of the atmosphere. At 70° it is somewhat fluid, though its fluidity is not perfect till it is heated to 150°. At 50° it is soft and malleable, and yields like wax to the pressure of the fingers; but it becomes brittle when cooled to 32°. It sublimes at a low red heat, without undergoing any change, provided atmospheric air be completely excluded. Its texture is crystaline, as may be seen by breaking it across while brittle, and cubical crystals of it have been obtained. In color and lustre it is very similar to lead. At 60° its density is 0.865, so that it is considerably lighter than water. It is quite opaque, and is a good conductor of heat and electricity.

The most prominent chemical property of potassium is its affinity for oxygen gas. It oxydizes rapidly in the air, or by contact with fluids which contain oxygen.

It decomposes water the instant it touches it, uniting with the oxygen, and sufficient heat is produced to inflame the potassium. When the potassium is kept under water violent reaction takes place, but without light, and pure hydrogen is evolved. Potassium burns with a beautiful rose-red flame.

596. On account of its strong affinity for oxygen, potassium is always preserved in glass tubes hermetically sealed, or under some liquid, as naphtha or oil of copaiba, neither of which contains oxygen.

This metal will even take fire and burn brilliantly in carbonic acid, if first heated to ignition. The oxygen combines with the potassium, and the carbon is deposited.

POTASSIUM AND OXYGEN.

There are two compounds of these substances, the protoxide and peroxide, composed as follows:

	Potassium.	*Oxygen.*	*Equiv.*	*Symbols.*
Protoxide	1 eq. +	1 eq.	47.15	KO
Peroxide	1 eq. +	3 eq.	63.15	KO_3

597. *Protoxide of Potassium.*—This compound, commonly called *potash* or *potassa*, and by the Germans, *kali* (an Arabic word), is always formed when potassium is put into water, or when it is exposed at common temperatures to dry air or oxygen gas. By the former method the protoxide is obtained in combination with water; and in the latter it is anhydrous. In performing the last-mentioned process, the potassium should be cut into very thin slices; for otherwise the oxydation is incomplete.

Anhydrous potassa is prepared by the slow oxydation of potassium, as already mentioned. In its pure state it is a white solid substance, highly caustic, which fuses at a temperature somewhat above that of redness, and bears the strongest heat of a wind furnace without being decomposed or volatilized. It has a powerful affinity for water, and intense heat is disengaged during the act of combination.

Three hydrates are known, which are composed of 47.15, or 1 eq. of potassa, united with 9.27, and 45 parts, or 1,3, and 5 eq. of water, respectively.

The *protohydrate* of potassa is solid at common temperatures. It fuses at a heat rather below redness, and assumes a somewhat crystaline texture in cooling. It is highly deliquescent, and requires about half its weight of water for solution. It is soluble, likewise, in alcohol. It destroys all animal textures, and on this account is employed in surgery as a caustic. It was formerly called *lapis causticus*, but it is now often termed *potassa* and *potassa fusa*. This preparation is made by evaporating the aqueous solution of potassa in a silver or clean iron capsule, to the consistence of oil, and then pouring it into moulds. In this state it is impure, containing oxide of iron, together with chloride of potassium, and carbonate and sulphate of potassa. It is purified from these substances by solution in alcohol; and evaporation to the same extent as before in a silver vessel. The operation should be performed expeditiously, in order to prevent, as far as possible, the absorption of carbonic acid. When common caustic potassa of the druggists is dissolved in water, a number of small bubbles of gas are disengaged, which is pure oxygen. The water cannot be expelled from this compound by any degree of heat to which it has been exposed. Its specific gravity is 1.71.

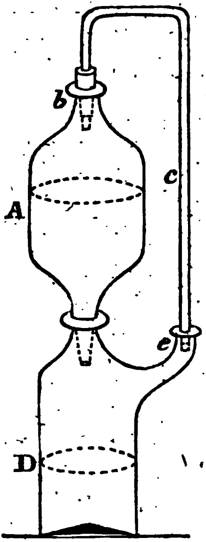
The *terhydrate* of potassa is formed by exposing the protohydrate to the air for a short time. At first it becomes moist very rapidly, but after a certain quantity of water has been absorbed, it again becomes dry and appears very much as at first, but is whiter, and its texture more crystaline. It is then found to contain three equivalents of water. The *quintohydrate* is obtained by exposing a very concentrated solution of potassa to an intense cold. It is then deposited in four-sided prisms, terminated by a four-sided pyramid, and sometimes in four-sided tables and octahedrons.

598. The aqueous solution of potassa, *aqua potassæ* of the pharmacopœia, is prepared by decomposing carbonate of potassa by lime. To effect this object completely, it is advisable to employ equal parts of quicklime and carbonate of potassa. The lime, as soon as it is slaked, is added to the carbonate, dissolved in ten times its weight of hot water, and the mixture is boiled briskly, in a clean iron vessel, for about ten minutes. The liquid, after subsiding, is filtered through a funnel, the throat of which is obstructed by a piece of clean linen. This process is founded on the fact that lime deprives carbonate of potassa of its acid, forming an insoluble carbonate of lime, and setting the pure alkali at liberty. If the decomposition is complete, the filtered solution should not effervesce when neutralized with an acid.

The decomposition of carbonate of potassa by lime takes place only when the solution is largely diluted with water, as above directed. On the contrary, carbonate of lime is itself decomposed by a strong solution of potassa.

599. As pure potassa absorbs carbonic acid rapidly when freely exposed to the atmosphere, it is desirable to filter its solution in vessels containing as small a quantity of air as possible. This is easily effected by means of the filtering apparatus devised by Donovan. It consists of two vessels A and D, of equal capacity, and connected with each other, as represented in figure 82. The throat of the upper vessel or funnel A is obstructed by a piece of coarse linen loosely rolled up, and

Fig. 82.



not pressed down into the pipe itself, through which the solution is filtered. The pipe *c*, extending from *e* to *b*, serves for the air to pass from the lower vessel to the upper; and the operation goes quietly on, free from contact with the atmosphere, except the little contained within the apparatus at the beginning of the process.

Solution of potassa is highly caustic, and its taste intensely acrid. It possesses alkaline properties in an eminent degree, converting the vegetable blue colors to green, and neutralizing the strongest acids. It absorbs carbonic acid gas rapidly, and is consequently employed for withdrawing that substance from gaseous mixtures. For the same reason it should be preserved in well-closed bottles, that it may not absorb carbonic acid from the atmosphere.

600. Potassa is employed as a reagent in detecting the presence of bodies, and in separating them from each other. The solid hydrate, owing to its strong affinity for water, is used for depriving gases of hygrometric moisture, and is admirably fitted for forming frigorific mixtures.

It is used extensively in the manufacture of soft soap by causing it to combine with tallow or other animal matter. For this purpose the carbonate it contains is rendered caustic by filtering the solution through recently slaked lime.

The potassa or potash of commerce is obtained by lixiviating the ashes of wood and other vegetable substances. It is a variable mixture of pure potassa, carbonate, and sulphate of potassa, and a variety of other substances. The pure potassa seldom exceeds twenty per cent. This subject will be again referred to under CARBONATE OF POTASSA.

601. Potassa may generally be very readily distinguished from all other substances except soda. When pure, or in the form of a carbonate, tartaric acid is a sufficient test, which forms with potassa a slightly soluble compound, bitartrate of potassa; but the corresponding salt of soda is highly soluble. When combined with a strong acid, potassa may be known by giving with chloride of platinum a yellow precipitate, the double chloride of platinum and potassium.

The following test has been recommended by M. Harkort, for distinguishing between potassa and soda in minerals. Oxide of nickel, when fused by the blowpipe flame with borax, gives a brown glass; and this glass, if melted with a mineral containing potassa, becomes blue, an effect which is not produced by the presence of soda.

602. *Peroxide of Potassium.*—When potassium burns in the open air in oxygen gas, it is converted into an orange-colored substance, which is peroxide of potassium. It may likewise be formed by conducting oxygen gas over potassa at a red heat; and it is produced in small quantity when potassa is heated in the open air. It is the residue of the decomposition of nitre by heat in metallic vessels, provided the temperature be kept up for a sufficient time. When the peroxide is put into water, it is resolved into oxygen and potassa, the former of which escapes with effervescence, and the latter is dissolved.

It may therefore be used, as has been suggested, to obtain oxygen extemporaneously.

POTASSIUM AND CHLORINE.

There is but one compound of potassium and chlorine.

	Potassium.	*Chlorine.*	*Equiv.*	*Symbol.*
Chloride of potassium	1 eq. +	1 eq.	74.57	KCl

603. *Chloride of Potassium.*—Potassium takes fire spontaneously in an atmosphere of chlorine, and burns with greater brilliancy than in oxygen gas. This chloride is generated with evolution of hydrogen when potassium is heated in hydrochloric acid gas; and it is the residue after the decomposition of chlorate of potassa by heat. It is formed when potassa is dissolved in a solution of hydrochloric acid, and is deposited by slow evaporation in anhydrous colorless cubic crystals. It has a saline and rather bitter taste, is insoluble in alcohol, and requires for solution 3 parts of water at 60°.

POTASSIUM AND IODINE.

	Potassium.	*Iodine.*	*Equiv.*	*Symbol.*
Iodide of potassium	1 eq. +	1 eq.	165.45	KI

604. *Iodide of Potassium.*—This compound is formed with evolution of heat and light, when potassium is heated in contact with iodine: it is the sole residue after decomposing iodate of potassa by heat; and by neutralizing potassa with hydriodic acid it is obtained in solution. The simplest process for preparing it in quantity is to add iodine to a hot solution of pure potassa until the alkali is neutralized, when iodide of potassium and iodate of potassa are generated, evaporate to dryness, and expose the dry mass in a platinum crucible to a gentle red heat, in order to decompose the iodate. The fused mass is then dissolved out by water and crystalized.

Iodide of potassium fuses readily when heated, and rises in vapor at a heat below full redness, especially in an open vessel. It is very soluble in water, requiring only two-thirds of its weight at 60° for solution, and in a moist atmosphere deliquesces. It dissolves also in strong alcohol, even in the cold, and the solution, when evaporated, yields colorless cubic crystals of iodide of potassium.

The commercial iodide is frequently impure, often containing chloride of potassium or sodium, and sulphate or carbonate of potassa, the last sometimes in a very large quantity. It is well to purchase it in crystals, which ought not to deliquesce in a moderately dry air, but when in powder are completely soluble in the strongest alcohol.

This substance is frequently sold under the name of *hydriodate of potassa.* It is properly a hydriodate only while in solution, always changing to iodide of potassium when evaporated to dryness. Under the name just mentioned, iodide of potassium is much used in medicine at the present time.

POTASSIUM AND SULPHUR.

Potassium and sulphur unite in five proportions, as indicated in the following table:

	Potassium.	*Sulphur.*	*Equiv.*	*Symbols.*
Sulphuret	1 eq.	+ 1 eq.	55.25	KS
Bisulphuret	1 eq.	+ 2 eq.	71.35	KS_2
Tersulphuret	1 eq.	+ 3 eq.	87.45	KS_3
Quadrosulphuret	1 eq.	+ 4 eq.	103.55	KS_4
Quintosulphuret	1 eq.	+ 5 eq.	119.65	KS_5

605. *Protosulphuret of Potassium.*—Potassium unites readily with sulphur by the aid of gentle heat, emitting so much heat that the mass becomes incandescent. The nature of the product depends on the proportions which are employed. The protosulphuret is readily prepared by decomposing sulphate of potassa by charcoal or hydrogen gas at a red heat. It may be prepared in the moist way by a process which will be mentioned in describing the sulphur-salts.

The *protosulphuret* of potassium fuses below a red heat, and acquires, on cooling, a crystaline texture. It has a red color, its taste is at first strongly alkaline and then sulphurous, has an alkaline reaction with test paper, deliquesces on exposure to the air, and is soluble in water and alcohol. Most of the acids decompose it with evolution of hydrosulphuric acid gas, and without any deposite of sulphur. It takes fire when heated before the blowpipe, and quickly acquires a coating of sulphate of potassa, which stops the combustion; but when mixed in fine division with charcoal, it kindles spontaneously, forming a good pyrophorus.

The tersulphuret, or, according to Thomson, the quintosulphuret, was formerly called *hepar sulphuris* or *liver of sulphur.*

These compounds, it will be observed, beautifully illustrate the third law of combination (321). It is thought there are some indications of a still higher degree of sulphuration.

POTASSIUM AND HYDROGEN.

606. These substances unite in two proportions, forming, in one case, a gaseous, and in the other, a solid compound. The former inflames spontaneously in the open air, and the latter is readily decomposed on coming in contact with water. The solid contains the least hydrogen.

Potassium combines also with bromine, fluorine, carbon, phosphorus, selenium, &c.

SODIUM.

Symbol Na; Equivalent 23.3.

607. Sodium, the *natrium* of the Germans, was discovered in 1807, by Davy, a few days after the discovery of potassium. The first portions of it were obtained by means of galvanism; but it may be procured in much larger quantity by chemical

processes, precisely similar to those just described for obtaining potassium.

Sodium has a strong metallic lustre, and in color is very analogous to silver. It is so soft at common temperatures, that it may be formed into leaves by the pressure of the fingers. It fuses at 200°, and rises in vapor at a red heat. Its specific gravity is 0.97.

Sodium soon tarnishes on exposure to the air, though less rapidly than potassium. Like that metal it is instantly oxydized by water, hydrogen gas in temporary union with a little sodium being disengaged. When thrown on cold water, it swims on its surface and is rapidly oxydized, though in general without inflaming; but with hot water it scintillates, or even takes fire. Indeed, the heat rises high enough for inflammation with cold water, if the sodium be confined to one spot, and the water rest on a non-conducting substance, such as charcoal. In each case soda is generated, and the water acquires an alkaline reaction.

Sodium burns with a beautiful yellow flame, which readily distinguishes it from potassium.

ALLOYS OF SODIUM.

618. Little is known of the alloys of the metals belonging to the first class. It is known, however, that sodium and potassium form an alloy which is so fusible that it is liquid at ordinary temperatures.

SODIUM AND OXYGEN.

Sodium and oxygen combine in two proportions, as indicated in the following table:

	Sodium.	*Oxygen.*	*Equiv.*	*Symbols.*
Protoxide	1 eq. +	1 eq.	31.3	NaO
Peroxide	2 eq. +	3 eq.	70.6	Na_2O_3

619. *Protoxide of Sodium.*—The protoxide of sodium, commonly called *soda*, and by the Germans, *natron*, is formed by the oxydation of sodium, as potassa is from potassium. In its anhydrous state, it is a gray solid, difficult of fusion, and very similar, in all its characters, to potassa. With water it forms a solid hydrate, easily fusible by heat, which is very caustic, soluble in water and alcohol, has powerful alkaline properties, and in all its chemical relations is exceedingly analogous to potassa. The solid hydrate is composed of 31.3 parts or one equivalent of soda, and 9 parts or one equivalent of water.

The soda of commerce is properly the carbonate or bicarbonate, generally the latter. From the carbonate of soda the pure caustic soda may be prepared in the same manner as caustic potassa.

620. Soda is readily distinguished from other alkaline bases

by the following characters. 1. It yields with sulphuric acid a salt, which by its taste and form is easily recognised as Glauber's salt, or sulphate of soda. 2. All its salts are soluble in water, and are not precipitated by any reagent. 3. On exposing its salts by means of platinum wire to the blowpipe flame, they communicate to it a rich yellow color. 4. It may easily be distinguished from potassa, the only substance for which it can ever be mistaken, by its forming a soluble salt with tartaric acid (611).

611. *Peroxide of Sodium.*—This compound is formed when sodium is heated to redness in an excess of oxygen gas. It has an orange color, has neither acid nor alkaline properties, and is resolved by water into soda and oxygen. There is some doubt concerning its actual composition.

SODIUM AND CHLORINE.

Sodium and chlorine combine with great energy, but only in a single proportion.

	Sodium.	*Chlorine.*	*Equiv.*	*Symbol.*
Chloride of sodium.........	1 eq. +	1 eq....	58.72....	NaO

612. *Chloride of Sodium.*—This compound may be formed directly by burning sodium in chlorine, by heating sodium in hydrochloric acid gas, and by neutralizing soda with hydrochloric acid. It exists as a mineral under the name of *rock salt*, is the chief ingredient of sea-water, and is contained in many saline springs. From these sources are derived the different varieties of common salt, such as rock, bay, fishery, and stoved salt, which differ from each other only in degrees of purity and mode of preparation.

The common varieties of salt, of which rock and bay salt are the purest, always contain small quantities of sulphate of magnesia and lime, and chloride of magnesium. These earths may be precipitated as carbonates by boiling a solution of salt for a few minutes with a slight excess of carbonate of soda, filtering the liquid, and neutralizing with hydrochloric acid. On evaporating this solution rapidly, chloride of sodium crystalizes in hollow four-sided pyramids; but it occurs in regular cubic crystals when the solution is allowed to evaporate spontaneously. These crystals contain no water of crystalization, but decrepitate remarkably when heated, owing to the expansion of water mechanically confined within them.

Pure chloride of sodium has an agreeably saline taste. It fuses at a red heat, and becomes a transparent brittle mass on cooling. It deliquesces slightly in a moist atmosphere, but undergoes no change when the air is dry. In pure alcohol it is insoluble. It requires twice and a half its weight of water at 60° for solution, and its solubility is not increased by heat. Hydrous sulphuric acid decomposes it with evolution of hydrochloric acid gas, and formation of sulphate of soda.

613. The uses of chloride of sodium are well known. Besides its employment in seasoning food, and in preserving meat from putrefaction, a property which, when pure, it possesses in a high degree, it is used for various purposes in the arts, especially in the formation of hydrochloric acid and bleaching salt.

614. This substance was formerly supposed to be hydrochlorate of soda, but it is found to be so only while in solution, if at all. In consequence of the great use made of it, particularly to preserve animal substances from putrefaction, and for seasoning food, it is prepared in almost every country, often in immense quantities. In England, Poland, and other countries, the mineral salt is dug up from beneath the soil, and purified by solution and evaporation; but in this country it is chiefly prepared from the brine of salt springs. The brine is evaporated by boiling, generally, but often by the heat of steam, or the sun's rays. More than 2,000,000 bushels are annually manufactured in the town of Salina, New York, alone. The brine here contains more than $\frac{1}{7}$ of its weight of pure salt.

615. The natural deposites of this substance are often very extensive; one in England is said to be half a mile long, 1300 yards wide, and 20 yards in thickness. Considerable search has been made in this country in the vicinity of brine springs for the solid deposite, but without success, till recently it has been found at no great depth beneath the surface, in the vicinity of Abingdon, Virginia.

In warm countries, as on the coast of Portugal, in the south of France, and the West India Islands, this substance is obtained by the spontaneous evaporation of sea-water, which is allowed, on the rise of the tide, to flow into shallow basins, being passed from one to another, as it becomes more concentrated, and finally, the evaporation being finished by means of artificial heat. Sea-water usually contains about 2.5 parts of chloride of sodium to 100 parts of the water, besides smaller proportions of several other compounds of magnesia and lime, which are often found in salt, but which are separated from it in the manufacture as much as possible.

It is worthy of remark that this substance, to which only, originally, the name *salt* was appropriated, and which subsequently gave name to an immense class of compounds, is itself, by our present technical arrangement, entirely excluded from the class.

Sodium forms definite compounds with iodine, bromine, fluorine, sulphur, &c., but they are not described in this work.

LITHIUM.

Symbol Li; Equivalent 6.4.

616. This is a white-colored metal, like sodium, which was first obtained by Davy, by means of galvanism; but it was reconverted into alkali so rapidly by the absorption of oxygen, that he did not succeed in collecting it in any quantity.

LITHIUM AND OXYGEN.

Lithium and oxygen form but a single compound, called *lithia*.

	Lithium.		*Oxygen.*	*Equiv.*	*Symbol.*
Lithia	1 eq.	+	1 eq.	14.4	LO

617. *Protoxide of Lithium, or Lithia.*—This compound was discovered in 1818, by Arfwedson, a pupil of Berzelius, in a mineral called petalite. It has since been detected in the minerals called spodumeme, lepidolite, tourmaline, &c., and in a solution in the waters of some mineral springs.

From the circumstance of its having been first obtained from an earthy mineral, it has received its present name; *lithia*, from λιθος, a stone. It has hitherto been procured in small quantity only, because spodumeme and petalite are rare, and do not contain more than 6 or 8 per cent. of the alkali. It is combined in these two minerals with silicic acid and alumina; whereas, potassa is likewise present in lepidolite and lithion-mica, and therefore, lithia should be prepared solely from the former.

The best method for preparing lithia is to mix intimately one part of petalite or spodumeme, in fine powder, with two parts of fluor spar, and three or four of sulphuric acid, and heat gently as long as any acid vapors escape. The silica is expelled in the form of fluo-silicic acid (481), and sulphates of alumina and lithia remain, from which the alumina is precipitated by boiling in solution of ammonia. The liquid, which is a solution of the sulphates of ammonia and lithia, is now to be evaporated to dryness, and the sulphate of ammonia expelled by heating the dry mass to redness. The residue is pure sulphate of lithia, which may be converted into a carbonate by decomposing it by acetate of baryta, and heating to redness the acetate of lithia thus obtained. The caustic hydrate may be formed from the carbonate by the action of lime, as directed for preparing hydrate of potassa.

Lithia, in its alkalinity, in forming a hydrate with water, and in its chemical relations, is closely allied to potassa and soda. It is distinguished from them by its greater neutralizing power, by forming sparingly soluble compounds with carbonic and phosphoric acids, and by its salts, when heated on platinum wire before the blowpipe, tinging the flame of a red color. Also, when fused on platinum foil, it attacks that metal, and leaves a dull yellow trace around the spot where it lay.

Lithium is capable of uniting with chlorine, fluorine, &c., but little is known of the nature of the compounds.

SECTION III.

METALLIC BASES OF THE ALKALINE EARTHS.

BARIUM.

Symbol Ba; Equivalent 68.7.

628. **Barium**, the metallic base of *baryta*, was discovered in the year 1808, by Davy, by a process suggested by Berzelius and Pontin. It consists in forming carbonate of baryta into a paste with water, placing a globule of mercury in a little hollow made in its surface, and laying the paste on a platinum tray which communicates with the positive pole of a galvanic battery of 100 double plates, while the negative wire is in contact with the mercury. The baryta is decomposed, and its barium combines with mercury. This amalgam is then heated in a vessel free from air, by which means the mercury is expelled, and barium obtained in a pure form.

By using the chloride of barium in contact with mercury in a powerful galvanic battery, Hare has succeeded in obtaining the metal in larger quantities than had before been found practicable.

Barium, thus procured, is of a dark grey color, with a lustre inferior to cast iron. It is far denser than water, for it sinks rapidly in strong sulphuric acid. It attracts oxygen with avidity from the air, and in doing so yields a white powder, which is baryta. It effervesces strongly, from the escape of hydrogen gas, when thrown into water, and a solution of baryta is produced.

BARIUM AND OXYGEN.

There are known at present but two compounds of barium and oxygen, the protoxide and the peroxide.

	Barium.	*Oxygen.*	*Equiv.*	*Symbols.*
Protoxide	1 eq. +	1 eq.	76.7	BaO
Peroxide	1 eq. +	2 eq.	84.7	BaO_2

629. *Protoxide of Barium.*—*Barytes*, or *baryta*, so called from the great density of its compounds, (from βαρυς, *heavy*,) was discovered in the year 1774, by Scheele. It is the sole production of the oxydation of barium in air and water. It may be prepared by decomposing nitrate of baryta at a red heat, or by exposing carbonate of baryta contained in a black lead crucible to an intense white heat; a process which succeeds much better when the carbonate is intimately mixed with charcoal. Baryta is a grey powder, the specific gravity of which is about 4. It requires a very high temperature for

fusion. It has a sharp caustic alkaline taste, converts vegetable blue colors to green, and neutralizes the strongest acids. Its alkalinity, therefore, is equally distinct as that of potassa or soda; but it is much less caustic and less soluble in water than those alkalies. In pure alcohol it is insoluble. It has an exceedingly strong affinity for water. When mixed with that liquid it slakes in the same manner as quicklime, but with the evolution of a more intense heat, which sometimes amounts to luminousness. The result is a white bulky hydrate, fusible at a red heat, and which bears the highest temperature of a smith's forge without parting with its water. It is composed of 76.7 parts or one equivalent of baryta, and 9 parts or one equivalent of water.

Hydrate of baryta dissolves in three times its weight of boiling water, and in twenty parts of water at the temperature of 60°. A saturated solution of baryta in boiling water deposites, in cooling, transparent, flattened, prismatic crystals, which are composed, according to Dalton, of 76.7 parts or one equivalent of baryta, and 180 parts or twenty equivalents of water; or, according to another analyst, one atom of baryta and ten atoms of water.

Both the sulphate and the carbonate of baryta are found native, but the former much the more frequently. It is therefore generally used in preparing the nitrate, from which the pure earth is itself obtained, as is above described.

To prepare the nitrate, the sulphate in fine powder is mixed with an eighth of its weight of powdered charcoal, and kept for some time at a white heat in a covered crucible; by which it is converted into a sulphuret of barium. This sulphuret is then easily decomposed by dilute nitric acid, nitrate of baryta is formed, and the sulphur deposited.

The aqueous solution of baryta is an excellent test of the presence of carbonic acid in the atmosphere, or in other gaseous mixtures. The carbonic acid unites with the baryta, and a white insoluble precipitate, carbonate of baryta, subsides.

630. Baryta is distinguished from all other substances by the following characters. 1. By dissolving in water and forming an alkaline solution. 2. By all its soluble salts being precipitated as white carbonate of baryta by alkaline carbonates, and as sulphate of baryta, which is insoluble both in acid and alkaline solutions, by sulphuric acid or any soluble sulphate. 3. By the characters of chloride of barium, formed by the action of hydrochloric acid on baryta.

Most of the compounds of baryta are highly poisonous, especially the more soluble ones. The sulphate being very insoluble, is inert.

631. *Peroxide of Barium.*—This oxide may be formed by passing a current of dry oxygen gas over baryta, at a low red heat; or by simply

heating baryta in an atmosphere of oxygen. It is used only for the purpose of preparing peroxide of hydrogen (392).

BARIUM AND CHLORINE.

	Barium.	*Chlorine.*	*Equiv.*	*Symbol.*
Chloride of Barium	1 eq. +	1 eq.	104.12	$BaCl$

622. *Chloride of Barium.*—Chloride of barium is formed when pure baryta is heated in chlorine, with the liberatien of oxygen gas, or by dissolving carbonate of baryta in hydrochloric acid diluted with 3 times its weight of water. On concentrating the solution, the chloride crystalizes, which contains 1 eq. of chloride and 18 eq. of water.

Chloride of barium is much used as a test for sulphuric acid, either free or in a state of combination. The two substances unite and form an insoluble white precipitate.

BARIUM AND SULPHUR.

	Barium.	*Sulphur.*	*Equiv.*	*Symbol.*
Sulphuret of Barium	1 eq. +	1 eq.	84.8	BaS

623. *Sulphuret of Barium.*—This compound may be formed by making the native sulphate of baryta in fine powder into a paste with flour, and exposing it in a close crucible to a white heat for one or two hours. The sulphuret is formed by the deoxydation of both the sulphuric acid and the base of the salt, the sulphur and the barium at the same time combining. The sulphuret being highly soluble may be separated from the mass by boiling water.

Sulphuret of barium possesses considerable interest, as from it the various salts of baryta, and indeed the pure earth itself, may readily be obtained. For this last purpose nitrate of baryta is first formed simply by the application of nitric acid.

Barium combines also with iodine, bromine, fluorine, phosphorus, &c.

STRONTIUM.

Symbol Sr ; Equivalent 43.8.

624. Davy discovered the metallic base of strontia, called *strontium*, by a process analagous to that described for procuring barium. All that is known respecting its properties is, that it is a heavy metal, similar in appearance to barium, that it decomposes water with evolution of hydrogen gas, and oxydizes quickly in the air, being converted in both cases into strontia, which is the protoxide of the metal.

STRONTIUM AND OXYGEN.

Strontium and oxygen form two compounds, the protoxide and the peroxide, which are composed as follows:

	Strontium.	*Oxygen.*	*Equiv.*	*Symbols*
Protoxide	1 eq. +	1 eq.	51.8	SrO
Peroxide	1 eq. +	2 eq.	59.8	SrO_2

625. *Protoxide of Strontium.*—From the close resemblance between baryta and strontia, these substances were once supposed to be identical; but the existence of strontia was established in the year 1792. It was originally extracted from strontianite, native carbonate of strontia, a mineral found at Strontian, in Scotland; and hence the origin of the term *strontites* or *strontia,* by which the earth itself is designated.

Pure strontia may be prepared from nitrate and carbonate of strontia, in the same manner as baryta. It resembles this earth in appearance, in infusibility, and in possessing distinct alkaline properties. It slakes when mixed with water, causing intense heat, and forming a white solid hydrate, which consists of 51.8 parts or one equivalent of strontia, and 9 parts or one equivalent of water. Hydrate of strontia fuses readily at a red heat, but sustains the strongest heat of a wind furnace without decomposition. It is insoluble in alcohol. Boiling water dissolves it freely; and a hot saturated solution, on cooling, deposites transparent crystals in the form of thin quadrangular tables, which consist of one equivalent of strontia and twelve equivalents of water. They are converted by heat into the protohydrate. They require fifty times their weight of water at 60° for solution, and twice their weight at 212°.

The solution of strontia has a caustic taste and alkaline reaction. Like the solution of baryta it is a delicate test of the presence of carbonic acid in air or other gaseous mixtures, forming with it the insoluble carbonate of strontia.

626. A striking characteristic of the compounds of strontia, by which they may generally be distinguished, is the crimson red flame they communicate to alcohol, holding them in solution. They also, when heated on a platinum wire before the blowpipe, give to the flame the same red tinge. The experimenter should, however, be careful to distinguish between the peculiar tinge occasioned by strontia, and that caused by lithia or lime.

The red lights used in fire-works, owe their color to nitrate of strontia, with which they are prepared.

Peroxide of Strontium.—This compound is formed by mixing solution of strontia with binoxide of hydrogen. It much resembles the corresponding oxide of barium, but is considered more permanent.

The chloride, iodide, fluoride, sulphuret, and phosphuret of strontium may easily be formed, but no description of them is given in this work.

CALCIUM.

Symbol Ca; Equivalent 20.5.

637. The existence of calcium, the metallic base of lime, was demonstrated by Davy, by a process similar to that described for obtaining barium. It is of a whiter color than barium or strontium, and is converted into lime by being oxydized. Its other properties are unknown.

CALCIUM AND OXYGEN.

These substances also unite in two proportions, forming definite compounds.

	Calcium.	*Oxygen.*	*Equiv.*	*Symbols.*
Protoxide	1 eq. +	1 eq.	28.5	CaO
Peroxide	1 eq. +	2 eq.	36.5	CaO_2

638. *Protoxide of Calcium.*—This compound, commonly known by the name of *lime* and *quicklime*, is obtained by exposing carbonate of lime to a strong red heat, so as to expel its carbonic acid. If lime of great purity is required, it should be prepared from pure carbonate of lime, such as Iceland spar or Carrara marble; but in burning lime in lime-kilns for making mortar, common limestone is employed. The expulsion of carbonic acid is facilitated by mixing the carbonate with combustible substances, in which case carbonic oxide is generated.

639. Lime is a brittle, white, earthy solid, the specific gravity of which is about 2.3. It phosphoresces powerfully when heated to full redness, a property which it possesses in common with strontia and baryta. It is one of the most infusible bodies known; fusing with difficulty even by the heat of the oxyhydrogen blowpipe.

Exposed to the air, it gradually absorbs carbonic acid and crumbles to powder. It has also a powerful affinity for water, which is absorbed instantly on being poured upon it; and the combination is attended with great increase of temperature, and formation of a white bulky hydrate, which is composed of 28.5 parts or one equivalent of lime, and 9 parts or one equivalent of water. The process of *slaking* lime consists in forming this hydrate, and the hydrate itself is called *slaked* lime. It differs from the hydrates of strontia and baryta, in parting with its water at a red heat.

Hydrate of lime is dissolved very sparingly by water, and it is a singular fact, that it is more soluble in cold than in hot water. Thus it is found that one grain of lime requires for solution

778	grains of water	at 60°
972	do.	130
1270	do.	212

And, consequently, on heating a solution of lime, or *lime-water*, which has been prepared in the cold, deposition of lime ensues.

At 32° it is found water will dissolve just twice as much lime as at the boiling point.

Lime-water is prepared by mixing hydrate of lime with water, agitating the mixture repeatedly, and then setting it aside in a well-stopped bottle until the undissolved parts shall have subsided. The substance called *milk* or *cream* of lime is made by mixing hydrate of lime with a sufficient quantity of water to give it the liquid form;—it is merely lime-water, in which hydrate of lime is mechanically suspended.

Lime-water has a harsh, acrid taste, and converts vegetable blue colors to green. It agrees, therefore, with baryta and strontia, in possessing distinct alkaline properties. On account of the affinity of lime for carbonic acid, its solution should be carefully protected from the air. By solution of carbonic acid it is first rendered turbid by the formation of carbonate of lime, but the transparency is restored by adding a larger quantity of the acid, because carbonate of lime is soluble in excess of carbonic acid. The action of this acid on the solutions of baryta and strontia is precisely similar.

640. Lime is made use of for many important purposes, particularly in the preparation of mortar for building. This mortar consists simply of a mixture of quicklime and siliceous matter made into a paste with water, and becomes very hard, by drying, in a short time. It has generally been supposed that this hardening, and subsequent insolubility in water, are to be attributed to its becoming a carbonate by the absorption of carbonic acid from the atmosphere; but it has been suggested with much plausibility that a partial solution of silica in the caustic lime probably takes place, causing the extreme hardness of the mortar, even in the middle of thick walls, where the carbonic acid of the atmosphere can hardly be supposed to penetrate.

641. There are, however, several different kinds of mortar, or cement, of which lime is the chief ingredient, besides common mortar, which has just been described. They are known by the names of *hydraulic cement*, and *Roman cement;* and though they differ in some respects from each other; the essential characteristic seems to be the same in both, and is probably to be attributed to the same cause. Mortar made of common lime, or lime nearly pure, can be made to set or become solid only in the air, though afterwards it resists perfectly the action of water; but mortar prepared from these cements, undergoes this change in moist places, or even under water. This, it is now well ascertained, is occasioned by chemical combination taking place between the lime and silica, and sometimes alumina, of which the cement is composed. When the lime is mixed intimately with ten per cent. of silica, mortar formed

from it partakes slightly of the hydraulic character, but it should contain from 20 to 30 per cent. in order to constitute hydraulic lime. Alumina alone mixed with lime does not produce the same effect; but combined with silica, it improves the cement. The best varieties of hydraulic lime are composed of from 60 to 80 parts of lime in 100, the remainder being about equal parts of silica and alumina.* Other substances, as magnesia and oxide of iron, are often present, but seem to produce no beneficial effects.

Hydraulic lime, or cement, as it is frequently called, is usually prepared from limestone, which contains the necessary ingredients, in the same manner as quicklime; but it may be formed artificially. The ancient Romans were accustomed to form an artificial cement, by mixing a volcanic stone called *puzzolana*, found at Puteoli, near Mount Vesuvius, with lime; and a basaltic rock called *tras* or *terras*, obtained from the banks of the Rhine, has, in modern times, been used for the same purpose. A mixture of 3 parts of chalk and one of common clay, well ground together and made into paste with water, and moulded in the form of bricks, affords by calcination and grinding an excellent cement.

632. Roman cement is a name given, some 40 or 45 years ago, to a cement prepared from a kind of stone found in nodules in the geological formation on which the city of London stands, called London clay. Specimens of it presenting a peculiar appearance, and sometimes susceptible of receiving a high polish, are called *septaria*. A similar rock is found in Cumberland, Maryland, and in Springfield, Massachusetts. The Roman cement obtained for a time great celebrity, but it is believed to be no better than other varieties of hydraulic lime, prepared in numerous places in our own country. Hydraulic, as well as common, or fat lime, is usually mixed with more or less sand when made into mortar.

633. The most delicate test of the presence of lime is oxalate of ammonia or potassa; for, of all the salts of lime, the oxalate is the most insoluble in water. This serves to distinguish lime from most substances, though not from baryta and strontia; because the oxalates of baryta and strontia, especially the latter, are likewise sparingly soluble. All these oxalates dissolve readily in water acidulated with nitric or hydrochloric acid. It is distinguished from baryta and strontia by the fact that nitrate of lime yields prismatic crystals by evaporation, is deliquescent in a high degree, and very soluble in alcohol: while the nitrates of baryta and strontia crystalize in regular octahedrons or segments of the octahedron, undergo no change on exposure to the air, except when it is very moist, and do not dissolve in pure alcohol.

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* These proportions are subject to great variations.

The salts of lime, when heated before the blowpipe, or when their solutions in alcohol are set on fire, communicate to the flame a dull brownish-red color.

634. *Peroxide of Calcium.*—This oxide is prepared in the same way as peroxide of barium, and is similar to it in its properties.

CALCIUM AND CHLORINE.

	Calcium.	*Chlorine.*	*Equiv.*	*Symbol.*
Chloride of Calcium	1 eq. +	1 eq.	55.92	$CaCl$

635. *Chloride of Calcium.*—This is the only compound of these two substances known. It may be prepared by heating lime in chlorine gas, or by dissolving carbonate of lime in hydrochloric acid and evaporating to dryness. It is produced in great abundance by the ordinary process of preparing aqua ammonia, and the carbonate of ammonia.

Owing to its strong affinity for water, it is much used to deprive gases and other substances of their moisture, and also for forming frigorific mixtures with snow.

CALCIUM AND FLUORINE.

	Calcium.	*Fluorine.*	*Equiv.*	*Symbol.*
Fluoride of Calcium	1 eq. +	1 eq.	39.18	CaF

636. *Fluoride of Calcium.*—This is a natural product, which frequently accompanies metallic ores, especially those of lead and tin, often occurs in cubic crystals, and is well known under the name of *fluor* or *Derbyshire spar*. The crystals found in the lead mines of Derbyshire are remarkable for their large size, the regularity of their form, and the variety and beauty of their colors.

Fluor spar is found abundantly in some parts of this country. In the northern part of New York cubic crystals a foot in each of their dimensions have been obtained, and of a variety of colors.

Fluoride of calcium fuses at a red heat without further change. It is insoluble in water, slightly soluble in hot diluted hydrochloric acid, and is decomposed by sulphuric acid aided by gentle heat (570). It is in a small degree decomposed by boiling nitric acid. Fused with carbonate of potassa, carbonate of lime and fluoride of potassium are generated.

The native fluoride of calcium is often cut into vases, and other ornamental articles, and is used as a flux in the smelting of metallic ores. It is from this last circumstance that it has received the name of fluor spar.

637. *Phosphuret of Calcium.*—It is formed by passing the vapor of phosphorus over fragments of quicklime at a low red heat; when a brown matter is formed, consisting of phosphate of lime and phosphuret of calcium. When put into water, phosphorous acid and phosphuretted hydrogen are produced; and the latter being in its spontaneously inflammable condition (515), is instantly ignited on coming in contact with the atmosphere.

638. The bromide, iodide, sulphuret, and seleniuret of calcium, are not of sufficient importance to require notice in this work.

MAGNESIUM.

Symbol Mg; Equivalent 12.7.

639. THE galvanic researches of Davy demonstrated the existence of magnesium, though he obtained it in a quantity too minute for determining its properties.

It has since been prepared in greater quantity by the action of potassium on the chloride of magnesium. For this purpose a few small pieces are put into a bent glass tube or very small retort, and covered with fragments of the chloride of magnesium. The heat of a spirit lamp is then applied; and the vapor of potassium coming in contact with the heated chloride, produces vivid incandescence by the transfer of the chlorine from the magnesium to the potassium. The chloride of potassium and undecomposed chloride of magnesium, are washed out with water, and metallic magnesium subsides.

Magnesium has a brilliant metallic lustre, and a white color like silver, is very malleable, and fuses at a red heat. Moist air oxydizes it superficially; but it undergoes no change in a dry air, and may be boiled in water without oxydation. Heated to redness in air or oxygen gas, it burns with brilliancy, yielding magnesia; and it inflames spontaneously in chlorine gas. It is readily dissolved by dilute acids with disengagement of hydrogen, and the solution is found to contain a pure salt of magnesia.

MAGNESIUM AND OXYGEN.

There is known but one oxide of magnesium.

	Magnesium.	*Oxygen.*	*Equiv.*	*Symbol.*
Protoxide of magnesium..	1 eq. +	1 eq......	20.7....	MgO

640. *Protoxide of Magnesium.*—This compound, so well known by the name of *magnesia*, is best obtained by exposing carbonate of magnesia to a very strong red heat, by which its carbonic acid is expelled. It is a white friable powder of an earthy appearance; and, when pure, it has neither taste nor odor. Its specific gravity is about 2.3, and it is exceedingly infusible. It has a weaker affinity than lime for water; for though it forms a hydrate when moistened, the combination is effected with hardly any disengagement of caloric, and the product is readily decomposed by a red heat.

The hydrate is found native, usually crystalized in thin laminæ. Magnesia dissolves very sparingly in water. It requires 5142 times its weight of water at 60°, and 36,000 of boiling water for solution. The resulting liquid does not change the color of violets; but when pure magnesia is put upon moistened turmeric paper, it causes a brown stain. From this there is no doubt that the inaction of magnesia with respect to vegetable colors, when tried in the ordinary mode, is owing to its insolubility. It possesses the still more essential character of alkalinity, that, namely, of forming neutral salts with acids in an eminent degree.

641. Magnesia is characterized by the following properties. With nitric and hydrochloric acids it forms salts which are soluble in alcohol and exceedingly deliquescent. The sulphate of magnesia is very soluble in water, a circumstance by which it is distinguished from the other alkaline earths. If moderately diluted, the salts of magnesia are not precipitated by oxalate of ammonia. By means of this reagent, magnesia may be both distinguished and separated from lime.

Magnesia is quite infusible in the strongest heat, and communicates this property to those minerals in which it predominates, as talc and steatite; which are therefore often used instead of fire-brick for lining furnaces.

Magnesia does not, like the other alkaline bases, absorb carbonic acid from the atmosphere, and but little if any water.

Other binary compounds of magnesium are the chloride, iodide, bromide, fluoride, and sulphuret.

SECTION IV.

METALLIC BASES OF THE EARTHS.

ALUMINUM.*

Symbol Al; Equivalent 13.7.

642. THAT alumina is an oxydized body was proved by Davy, who found that potassa is generated when the vapor of potassium is brought into contact with pure alumina heated to whiteness; and its metallic base *aluminum* has since been obtained in a separate state.

The preparation of this metal depends on the property which potassium possesses of decomposing the chloride of aluminum. Decomposition is effected by aid of a moderate increase of temperature; but the action is violent, accompanied with intense heat.

Platinum, or, which is better, porcelain crucibles, should therefore be always used; and the potassium should be free from carbon.

When *quite cold*, the crucible is put into a large glass full of water, in which the saline matter is dissolved, and a grey powder separates, which, on close inspection, especially in sunshine, is found to consist solely of minute scales of metal. These scales, after being well washed with *cold* water, are pure aluminum.

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* This word is uniformly written aluminum instead of aluminium, on the authority of Thomson, Donovan, Beck, Kane, and others.

Aluminum, as thus formed, is generally in small scales or spangles of a metallic lustre; but sometimes small, slightly coherent, spongy masses are observed, which in some places have the lustre and white color of tin.

When fused, which requires a very high temperature, it is a conductor of electricity, but not in a state of powder, as it is first formed.

Heated to redness in the open air, it readily takes fire, and burns with a vivid light, and in oxygen gas it burns with still greater brilliancy; so much heat is evolved that the resulting alumina is partially vitrified, and equal in hardness to the native crystalized aluminous earth, *corundum*.

Water, at ordinary temperatures, produces no effect upon it, but slight oxydation takes place when it is heated nearly to the boiling point. None of the acids act upon it when cold.

ALUMINUM AND OXYGEN.

Aluminum combines with oxygen in single proportion only, as follows:

	Aluminum.	*Oxygen.*	*Equiv.*	*Symbol.*
Sesquioxide of aluminum	2 eq. +	3 eq.	51.4	Al_2O_3

643. *Sesquioxide of Aluminum.*—This compound is well known under the name of *alumina* or *aluminous earth*. It is one of the most abundant productions of nature. It is found in every region of the globe, and in rocks of all ages, being a constituent of the oldest primary mountains, of the secondary strata, and of the most recent alluvial depositions. The different kinds of clay, of which bricks, pipes, and earthenware are made, consist of hydrate of alumina in a greater or less degree of purity. Though this earth commonly appears in rude amorphous masses, it is sometimes found beautifully crystalized. The ruby and the sapphire, two of the most beautiful gems with which we are acquainted, are composed almost solely of alumina.

Pure alumina is prepared from alum, sulphate of alumina and potassa. Any quantity of alum is dissolved in four or five times its weight of boiling water, a slight excess of carbonate of potassa added, and after digesting for a few minutes, the bulky hydrate of alumina is collected on a filter, and well washed with hot water.

The alum of commerce is not pure, being usually contaminated with peroxide of iron, and consequently unfit for many chemical purposes; but it may be separated from this impurity by repeated crystalization. Its absence is proved by the alum being soluble without residue in a solution of pure potassa; whereas, when peroxide of iron is present, it is either left undissolved in the first instance, or deposited after a few hours in yellowish-brown flocks.

Another process which has been proposed for procuring alumina, is to expose sulphate of alumina and ammonia to a strong heat, to expel the ammonia and sulphuric acid.

644. Alumina has neither taste nor smell, and is quite insoluble in water. It is very infusible, though less so than lime or magnesia. It has a powerful affinity for water, attracting moisture from the atmosphere with avidity; and for a like reason, it adheres tenaciously to the tongue, when applied to it. Mixed with a due proportion of water, it yields a soft cohesive mass, susceptible of being moulded into regular forms, a property upon which depends its employment in the art of pottery. When once moistened it cannot be rendered anhydrous, except by exposure to a full white heat; and in proportion as it parts with water, its volume diminishes.

Alumina, owing to its insolubility, does not affect the blue color of plants. It appears to possess the properties both of an acid and of an alkali:—of an acid, by uniting with alkaline bases, such as potassa, lime, and baryta; and of an alkali, by forming salts with acids. In neither case, however, are its insoluble compounds neutral with respect to test paper. It forms with water several different compounds.

This earth is remarkable for its tendency to unite with organic substances. If a cotton cloth is immersed in a solution of acetate of alumina, the earth will deposite itself completely on the fibres of the cotton and leave the acetic acid free. On this principle depend some of the most important processes in calico-printing.

Alumina is easily recognized by the following characters. 1. It is separated from acids, as a hydrate, by all the alkaline carbonates, and by pure ammonia. 2. It is precipitated by pure potassa or soda, but the precipitate is completely redissolved by an excess of the alkali.

Alumina is considered a sesquioxide of aluminum, but there is some difficulty in determining the question, as the metal is not known to combine with any substance in more than one proportion.

Aluminum unites also with chlorine, sulphur, phosphorus, and selenium; and it is a little remarkable that with all it forms *sesqui* compounds!

GLUCINUM.

Symbol G; Equivalent 26.5.

645. GLUCINA, which was discovered by Vauquelin in the year 1798, has hitherto been found only in three rare minerals, the euclase, beryl, and emerald. From this earth metallic glucinum is prepared, by a process similar to that for obtaining metallic aluminum.

646. *Sesquioxide of Glucinum.*—This oxide is commonly prepared from beryl, in which it exists, to the extent of about 14 per cent., combined with silicic acid and alumina. It is a white powder, and receives its name, *glucina*, (from γλυκυς, *sweet*,) from the fact that its salts possess a distinct sweetish taste. It is distinguished from alumina, which it much resembles, by being completely soluble in solution of carbonate of ammonia.

YTTRIUM.

Symbol Y; Equivalent 32.2.

647. YTTRIUM is the metallic base of an earth which was discovered by Professor Gadolin, at Ytterby, in Sweden, in the year 1794. The earth was therefore called *yttria*. The mineral from which it is obtained is called *gadolinite*, in honor of the discoverer.

Yttria is considered a protoxide of the metal.

THORIUM

Symbol Th; Equivalent 59.6.

648. THORIUM is the metallic base of an earth called *thorina*, or sometimes *thoria*. It was discovered by Berzelius, in 1828. It is obtained from a mineral found in Norway, called *thorite*.

The earth thorina, or thoria, is found only in minute quantities, but is well distinguished from other substances. It is considered a protoxide.

ZIRCONIUM.

Symbol Zr; Equivalent 33.7.

649. THIS metal was first obtained by Berzelius, in 1824, by heating with a spirit-lamp, a mixture of potassium and the double fluoride of zirconium and potassium, carefully dried, in a tube of glass or iron. The reduction takes place, at a temperature below redness, without emission of light; and the mass is washed with boiling water, and afterwards digested for some time in dilute hydrochloric acid. The residue is pure zirconium.

Zirconium, thus obtained, is in the form of a black powder, which may be boiled in water without being oxydized, and is attacked with difficulty by sulphuric, hydrochloric, or nitrohydrochloric acid; but it is dissolved readily, and with disengagement of hydrogen gas, by hydrofluoric acid Heated in the open air, it takes fire at a temperature far below luminousness, burns brightly, and is converted into zirconia. Its metallic nature seems somewhat questionable. It may indeed be pressed out into thin shining scales of a dark grey color, and of a lustre which may be called metallic; but its particles cohere together very feebly, and it has not been procured in a state capable of conducting electricity. These points, however, require further investigation before a decisive opinion on the subject can be adopted.

650. *Oxide of zirconium, or zirconia,* was first obtained in the year 1789, from a mineral found in Ceylon, called jargon, or zircon. Hence its name.

Crystals of zirconia are now found in different parts of our own country in Buncombe County, N. C., at Easton, Pa., and in Munroe and Haddam in the state of Connecticut.

SECTION V.

METALS WHICH DECOMPOSE WATER AT A RED HEAT.

MANGANESE.

Symbol Mn, Equivalent 27.7.

651. THIS metal, owing doubtless to its strong affinity for oxygen, has never been found in an uncombined state in the earth; but its oxides are very generally diffused though not very abundant. The metal may be obtained by forming finely powdered oxide of manganese into a paste with oil, laying the mass in a Hessian crucible lined with charcoal, luting down a cover carefully, and exposing it during an hour and a half or two hours to the strongest heat of a smith's forge. But the experiment is one of considerable difficulty. Its name is a modification of magnesia, its native peroxide having formerly been called *magnesia nigra.*

652. Manganese is a hard, brittle metal, of a greyish white color, and granular texture. Its specific gravity is 8.01. It is exceedingly infusible, requiring the highest heat of a wind furnace for fusion. It soon tarnishes on exposure to the air, and absorbs oxygen with rapidity when heated to redness in open vessels. It slowly decomposes water at common temperatures with disengagement of hydrogen gas; but at a red heat decomposition is rapid, and protoxide of manganese is generated. Decomposition of water is likewise occasioned by dilute sulphuric acid, and sulphate of protoxide of manganese is the product.

MANGANESE AND OXYGEN.

Many distinguished chemists have expended much labor in investigating the oxides of manganese, which they have found a subject of considerable difficulty. The following distinct compounds are, however, generally recognized at the present time.

	Manganese.		*Oxygen.*	*Equiv.*	*Symbols.*
Protoxide	1 eq.	+	1 eq.	35.7	MnO
Sesquioxide	2 eq.	+	3 eq.	79.4	Mn_2O_3
Peroxide	1 eq.	+	2 eq.	43.7	MnO_2
Red oxide	3 eq.	+	4 eq.	115.1	Mn_3O_4
Varvicite	4 eq.	+	7 eq.	166.8	Mn_4O_7
Manganic acid	1 eq.	+	3 eq.	51.7	MnO_3
Permanganic acid	2 eq.	+	7 eq.	111.4	Mn_2O_7

In studying metallic oxides, it is necessary to distinguish oxides formed by the direct union of oxygen and a metal, from those that consist of two other oxides united with each other, and which, therefore, in composition, partake of the nature of a salt rather than of an oxide. An instance of this kind of combination is supplied by the black oxide of iron; and it is probable that two, if not three, of the five compounds enumerated as oxides of manganese, have a similar constitution. Thus, the red oxide may be composed of one equivalent of the protoxide combined with one equivalent of the sesquioxide.

653. *Protoxide of Manganese.*—By this term is meant that oxide of manganese which is a strong salifiable base, is contained in all the ordinary salts of this metal, and which appears to be its lowest degree of oxydation. This oxide may be formed by exposing the peroxide, sesquioxide, or red oxide of manganese, to the combined agency of charcoal and a white heat.

It may also be prepared by passing a current of hydrogen over either of the other oxides, heated to redness in a porcelain tube; or by fusing the chloride of manganese in a platinum crucible, with about twice its weight of carbonate of soda, and afterwards dissolving the chloride of sodium by water.

654. Protoxide of manganese, when pure, is of a light green color, very near the mountain green. Some experimenters have observed it attract oxygen very rapidly from the atmosphere, and pass into the peroxide; but as prepared by others, it has remained quite permanent, undergoing little change for many days. This difference is probably to be attributed to the different methods of preparing it. At 600° it is oxydized with considerable rapidity, and at a low red heat is converted in an instant into red oxide. It sometimes takes fire when thus heated, especially when the mass is considerable.

655. *Sesquioxide of Manganese.*—This oxide occurs nearly

pure in nature, and as a hydrate it is found abundantly, often in large prismatic crystals. It may be formed artificially by exposing peroxide of manganese for a considerable time to a moderate red heat, and, therefore, is the chief residue of one process (364) for procuring a supply of oxygen gas; but it is difficult so to regulate the degree and duration of the heat, that the resulting oxide shall be quite pure.

The color of the sesquioxide of manganese varies with the source from which it is derived. That which is procured by means of heat from the native peroxide or hydrated sesquioxide has a brown tint; but when prepared from nitrate of oxide of manganese, it is nearly as black as the peroxide, and the native sesquioxide is of the same color. From the proportion of oxygen and manganese in this oxide, it may be regarded as a compound of one equivalent of the protoxide, and one equivalent of the peroxide.

This oxide has the property of staining glass purple or violet, for which purpose it is sometimes used. By this character a very small trace of manganese can be detected by fusing the substance supposed to contain it in the oxydizing flame of the blowpipe.

Peroxide of Manganese.—This is the well-known ore commonly called, from its color, *black oxide* of manganese. It generally occurs massive, of an earthy appearance, and mixed with other substances, such as siliceous and aluminous earths, oxide of iron, and carbonate of lime. It is sometimes found, on the contrary, in the form of minute prisms grouped together, and radiating from a common centre. In these states it is anhydrous; but the essential ingredient of one variety of the earthy mineral, called *wad*, is hydrated peroxide of manganese, consisting of one equivalent of water and two of the oxide.

Peroxide of manganese undergoes no change on exposure to the air. It is insoluble in water, and does not unite either with acids or alkalies. When boiled with sulphuric acid it yields oxygen gas, and a sulphate of the protoxide is formed (364). With hydrochloric acid, chloride of manganese is generated, and chlorine is evolved (531). The action of sulphuric acid in the cold is exceedingly tardy and feeble, a minute quantity of oxygen gas is slowly disengaged, and the acid acquires an amethyst-red tint. On exposure to a red heat, it is converted, with evolution of oxygen gas, into the sesquioxide of manganese (364).

Peroxide of manganese is employed in the arts, in the manufacture of glass, and in preparing chlorine for bleaching. In the laboratory it is used for procuring chlorine and oxygen gases, and in the preparation of the salts of manganese.

The appearance of the sesquioxide of manganese so nearly resembles that of the peroxide, that the former is often fraudulently sold for the latter. The sesquioxide of course yields only half as much oxygen; and though it may be used in preparing chlorine, it will not yield any oxygen by the application of heat alone.

656. *Red Oxide of Manganese.*—The substance called red oxide of manganese, *oxidum-manganoso-manganicum* of Arfwedson, occurs as a natural production, and may be formed artificially by exposing the peroxide or sesquioxide to a white heat. It may also be formed artificially by other means.

This compound (as well as the protoxide and varvicite,) should perhaps rather be considered as a salt than an oxide (299). It may be composed either of 1 eq. of the sesquioxide and 1 eq. of the protoxide, or 1 eq. of the peroxide united to 2 eq. of the protoxide. Thus $Mn_2O_3+MnO=Mn_3O_4$ and $2MnO+MnO_2=Mn_3O_4$.

657. *Varvicite.*—This compound is known only as a natural production, having been first noticed a few years ago among some ores of manganese found at Hartshill, in Warwickshire, Eng. The locality of the mineral suggested its name. It is probably a compound of two equivalents of the peroxide, and one equivalent of the sesquioxide. Thus $2MnO_2+Mn_2O_3=Mn_4O_7$.

658. *Manganic Acid.*—When equal weights of peroxide of manganese and carbonate or nitrate of potassa are intimately mixed and heated to redness, oxygen is absorbed by the manganese, and manganic acid is formed, which by its union with the potassa produces manganate of potassa. This compound, which is of a dark green color, has long been known by the name of *mineral chameleon*, from the property of its solution to pass rapidly through several shades of color. On the first addition of cold water, a green solution is formed, which soon becomes blue, purple, and red; and ultimately a brown flocculent matter, hydrated peroxide of manganese, subsides, and the liquid becomes colorless.

These phenomena are owing to the formation of manganate of potassa which is green, and its ready conversion into the red permanganate of potassa—the blue and purple tints being due to a mixture of these compounds. Manganic acid itself cannot be obtained in an uncombined state, because it is then resolved into the hydrated peroxide and oxygen.

Manganate of potassa may be obtained in crystals from solution of mineral chameleon, but the process requires great care.

659. *Permanganic Acid.*—This acid is more stable than the manganic, though itself very prone to decomposition. Contact with paper or linen as in filtering, particles of cork, organic particles floating in the atmosphere decompose it rapidly; coloring matters are bleached by it, and in pure water its decomposition begins at 86°, and is complete at 212°.

The salts of permanganic acid are more permanent than the free acid; so that most of them may be boiled in solution, especially if concentrated. Permanganate of potassa is obtained by heating a green solution of mineral chameleon, and by other processes.

The salts formed by this acid contain so much oxygen, and yield it so readily, that they deflagrate like nitre with burning charcoal, and detonate powerfully with phosphorus.

For a description of the chlorides, iodide, fluoride, phosphuret, and sulphuret of manganese, see other more extended works on chemistry.

IRON.

Symbol Fe; Equivalent 28.

660. Iron, the most abundant and most useful of all the metals, has been known from the remotest antiquity. The ores of the metal, as well as the metal itself, and some of its manufactures, are mentioned in the writings of Moses;* and it is well known the ancient Greeks and Romans were acquainted with it.

661. Iron has been found native in Guilford County, North Carolina, and in Canaan, Connecticut, and also in Russia, but only in small quantities. The occurrence of iron of meteoric origin, associated with nickel and often with cobalt, is, however, very common. Masses of this character often of great magnitude, called *aerolites*, have been seen to fall from the high regions of the atmosphere, apparently in a state of vivid ignition or combustion. Their course is always much inclined to the horizon, and before striking the surface they often burst into fragments, which bury themselves deep in the soil. As no locality on the earth affords such compounds of iron, nickel, and other substances, the only theory which can explain their origin is, that they have been violently expelled from the volcanoes which are known to exist on the surface of the moon, and that, passing beyond the limits of her attraction, and coming within that of the earth, they are thus brought to its surface.†

In combination with oxygen and sulphur, and other elementary substances, iron is abundant; being contained in animals and plants, and being diffused so generally in the earth, that there are few mineral substances in which its presence may not be detected. Minerals which contain iron in such form, and in such quantity, as to be employed in the preparation of the metal, are called *ores of iron*, of which mineralogists have described no less than forty-seven different species. But the following are the only ones used to any extent for the extraction of the metal:

The red oxides of iron, included under the name of red hematite; the brown hematite of mineralogists, consisting of hydrated peroxide of iron; the black oxide, or magnetic iron ore; and carbonate of protoxide of iron, either pure, or in the form of clay iron ore, when it is mixed with siliceous, aluminous, and other foreign substances. The three former occur most abundantly in primary districts, and supply the finest kinds of iron, as those of Sweden and India; while clay-iron stone, from which most of the English iron is extracted, occurs in secondary deposites, and chiefly in the coal formation.

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* Deut. iv, 20; viii, 9; xviii, 5; xxvii, 5; Numb. xxxv, 16; Levit. i, 17.

† A mass of meteoric iron, weighing 1635 pounds, containing 9 or 10 per cent. of nickel, was found, many years ago, on a branch of the Red River in Louisiana. It is now in the cabinet of Yale College.

Most American iron is extracted, it is believed, from the brown hematite and the protoxide; but the red hematite and carbonate, called also *spathic iron* and *steel ore*, are also used to some extent.

662. The extraction of iron from its ores is effected by exposing the ore, previously roasted and reduced to a coarse powder, to the action of charcoal or coke, and lime, at a high temperature. The action of carbonaceous matter, in depriving the ore of its oxygen, is obvious; and the lime plays a part equally important. It acts as a flux by combining with all the impurities of the ore, and forming a fusible compound called a *slag*. The whole mass being thus in a fused state, the particles of reduced metal descend by reason of their greater density, and collect at the bottom; while the slag forms a stratum above, protecting the melted metal from the action of the air. The latter, as it collects, runs out at an aperture in the side of the furnace; and the fused iron is let off by a hole in the bottom, which was previously filled with sand. The process is never successful unless the flux, together with the impurities of the ore, is in such proportion as to constitute a fusible compound. The mode of accomplishing this object is learned only by experience; and as different ores commonly differ in the nature or quantity of their impurities, the workman is obliged to vary his flux according to the composition of the ore with which he operates. Thus if the ore is deficient in siliceous matter, sand must be added; and if it contain a large quantity of lime, proportionally less of that earth will be required. Much is often accomplished by the admixture of different ores with each other. The slag consists of a compound of earthy salts, similar to some siliceous minerals, in which silicic acid is combined with lime, alumina, magnesia, protoxide of manganese, and sometimes oxide of iron. The most usual combination is bisilicate of lime and magnesia, sometimes with a little protoxide of iron; a compound which may be obtained in crystals, having the precise form and composition of pyroxene. Artificial minerals may, in fact, by such processes, be procured, similar in form and composition to those which occur in the earth.

663. The iron obtained by this process is the *cast-iron* of commerce, and contains a considerable quantity of carbon, unreduced ore, and earthy substances. It is converted into soft or malleable iron, by exposure to a strong heat, while a current of air plays upon its surface, or is forced through it. By this means any undecomposed ore is reduced, earthy impurities rise to the surface, as slag, and carbonaceous matter is

burned. The exposed iron is also more or less oxydized at its surface, and the resulting oxide, being stirred with the fused metal below, facilitates the oxydation of the carbon. As the purity of the iron increases, its fusibility diminishes, until at length it begins to *work heavy*, as the workmen term it; and though the temperature is kept the same, or is even raised, the iron becomes solid. It is then subjected, while still hot, to the operation of rolling or hammering, by which its particles are approximated, and its tenacity greatly increased. It is then the malleable iron of commerce. It is not, however, absolutely pure; for Berzelius has detected in it about one-half per cent. of carbon, and it likewise contains traces of silicon. The carbonaceous matter may be removed by mixing iron filings with a quarter of its weight of black oxide of iron, and fusing the mixture, confined in a covered Hessian crucible, by means of a blast furnace. A little powdered green glass should be laid on the mixture, in order that the iron may be completely protected from the air by a covering of melted glass, and any unreduced oxide dissolved. But the best and readiest mode of procuring iron in a state of perfect purity, is by transmitting hydrogen gas over the pure oxide heated to redness in a tube of porcelain. The oxygen of the oxide unites with hydrogen, and the metal is left in the form of a porous spongy mass.

Owing probably to the extremely divided and expanded state of the metallic iron when reduced in this manner, it often takes fire spontaneously, and the oxide is instantly reproduced. This, however, is observed only when the reduction is effected at a temperature below redness, and not when the heat is raised so as to produce partial fusion and of course greater compactness.

664. Iron has a peculiar grey color, and strong metallic lustre, which is susceptible of being heightened by polishing. In ductility and malleability it is inferior to several metals, but exceeds them all in tenacity (579). At common temperatures it is very hard and unyielding, and its hardness may be increased by being heated and then suddenly cooled; but it is at the same time rendered brittle. When heated to redness it is remarkably soft and pliable, so that it may be beaten into any form, or be intimately incorporated or *welded* with another piece of red-hot iron, by hammering. Its texture is fibrous. Its specific gravity may be estimated at 7.7; but it varies slightly, according to the degree with which it has been rolled, hammered, or drawn, and it is increased by fusion. In its pure state it is exceedingly infusible, requiring for fusion the highest temperature of a wind-furnace. It is attracted by the magnet, and may itself be rendered permanently magnetic by several processes;—a property of great interest and importance, and which is possessed by no other metal excepting nickel. And

this possesses the property in a degree much inferior to that of iron.

Iron, in its ordinary state, has a strong affinity for oxygen. In a perfectly dry atmosphere it undergoes no change; but when moisture is likewise present, its oxydation, or *rusting*, is rapid. At first, protoxide of iron is formed, which soon absorbs carbonic acid from the atmosphere; but this gradually passes into hydrated peroxide, the carbonic acid being evolved. Rust of iron always contains ammonia, which is also often found in the native oxides of iron, indicating the decomposition of water during their formation.

Heated to redness in the open air, iron absorbs oxygen rapidly, and is converted into black scales, called the *black oxide* of iron; and in an atmosphere of oxygen gas it burns with vivid scintillations. It decomposes the vapor of water, by uniting with its oxygen, at all temperatures, from a dull red to a white heat.

665. A remarkable property of iron, though not peculiar to it alone, has recently been discovered. It is found that under certain circumstances, it becomes entirely passive, as it regards the action of nitric acid of sp. gravity 1.35 upon it, though ordinarily, it would be dissolved by it with great violence. Various means have been discovered by which it may be rendered thus passive, as by making it the positive electrode of a galvanic battery, the negative electrode having been previously introduced into the acid, by mere contact of one iron wire with another, or by heating one end of the wire before introducing it into the acid. Nor is the effect limited to nitric acid, but extends to various saline solutions that usually act upon iron. The subject has not yet been sufficiently investigated to lead to a full explanation of the phenomena.

IRON AND OXYGEN.

There are properly but two oxides of iron, the black oxide, as it is called, being a definite compound of the other two.

	Iron.	*Oxygen.*	*Equiv.*	*Symbols.*
Protoxide	1 eq.	+ 1 eq.	36	FeO
Sesquioxide	2 eq.	+ 3 eq.	80	Fe_2O_3
Black Oxide	Protoxide 1 eq. Sesquioxide 1 eq.		116	FeO, Fe_2O_3

666. *Protoxide of Iron.*—This oxide is the base of the native carbonate of iron, and of the green vitriol of commerce. Its salts, particularly when in solution, absorb oxygen from the atmosphere with such rapidity that they may even be employed in eudiometry. This protoxide is always formed with evolution of hydrogen gas, when metallic iron is put into dilute sulphuric acid; and its composition may be determined by collecting and measuring the gas which is disengaged. It has not been obtained in a separate state.

Protoxide of iron is precipitated from its salts as a white hydrate by pure alkalies, as a white carbonate by alkaline carbonates, and as a white ferrocyanide by ferrocyanide of potassium. The two former precipitates become first green and then red, and the latter, green and blue, by exposure to the air. The solution of gall-nuts produces no change of color.

667. *Sesquioxide of Iron.*—The red or sesquioxide of iron, sometimes also called the peroxide, is a natural product, known to mineralogists under the name of *red hematite.* It sometimes occurs massive, at other times fibrous, and occasionally in the form of beautiful rhomboidal crystals.

This oxide is not attracted by the magnet. Fused with vitreous substances, it communicates to them a red or yellow color. It combines with most of the acids, forming salts, the greater number of which are red. Its presence may be detected by very decisive tests. The pure alkalies, fixed or volatile, precipitate it as the hydrate. The hydrate above mentioned, in its pulpy state, as first formed, is found to be an excellent remedy for arsenious acid. With ferrocyanide of potassium it forms *Prussian blue,* which circumstance affords a very delicate test. Infusion of nut-galls forms with it a black precipitate, which is the basis of black writing ink.

The polishing powder, well known in the arts under the name of *rouge* or *colcothar,* is sesquioxide of iron prepared from green vitriol by expelling its acid by heat.

668. *Black Oxide.*—This substance, long regarded as the protoxide, is really a compound of the protoxide and peroxide. It occurs native, frequently crystalized in the form of a regular octahedron; and it is not only attracted by the magnet, but is itself sometimes magnetic, and is then called *loadstone.* It is always formed when iron is heated to redness in the open air; and is likewise generated by the contact of watery vapor with iron at elevated temperatures.

IRON AND CHLORINE.

There are two chlorides of iron, the protochloride and the sesquichloride, composed as follows:

	Iron.		*Chlorine.*	*Equiv.*	*Symbols.*
Protochloride	1 eq.	+	1 eq.	63.42	FeCl
Sesquichloride	2 eq.	+	3 eq.	162.26	Fe_2Cl_3

669. *Protochloride of Iron.*—This compound is formed by transmitting dry hydrochloric acid gas over iron at a red heat, or by dissolving iron in dilute hydrochloric acid, evaporating to dryness, and heating to redness without exposure to air.

Protochloride of iron dissolves freely in water, yielding a pale green solution, from which rhomboïdal prisms of the same color are obtained by evaporation.

670. *Sesquichloride of Iron.*—The sesquichloride of iron may be formed either by the combustion of iron wire, in dry chlorine gas, or by dissolving the sesquioxide in hydrochloric acid. By evaporation and cooling, it may

be obtained in red crystals, which are soluble in water or alcohol. This chloride forms the basis of the *tincture muriatis ferri*, used in medicine.

IRON AND SULPHUR.

Iron and sulphur have a strong affinity for each other, and form by their union the five following compounds:

	Iron.		*Sulphur.*	*Equiv.*	*Symbols.*
Tetrasulphuret	4 eq.	+	1 eq.	128.2	Fe_4S
Disulphuret	2 eq.	+	1 eq.	72.1	Fe_2S
Protosulphuret	1 eq.	+	1 eq.	44.1	FeS
Sesquisulphuret	2 eq.	+	3 eq.	104.3	Fe_2S_3
Bisulphuret	1 eq.	+	2 eq.	60.2	FeS_2

The chief object in introducing the above table is to keep before the mind the perfect conformity of facts to the laws of definite proportions, and to illustrate further the principles of the chemical nomenclature. The student is requested to mark the distinction between *tetrasulphuret* and a *quadrosulphuret* of a base.

It should be remarked that some consider the existence of the first two in the above table as problematical.

671. *Protosulphuret of Iron.*—This sulphuret of iron is formed by heating to redness, a mixture of iron filings or turnings and sulphur, in a covered crucible, and raising the temperature after the cover is removed so as to expel the excess of sulphur. It is completely dissolved by dilute sulphuric acid, with formation of sulphate of the protoxide of iron, and hydrosulphuric acid.

672. *Bisulphuret of Iron.*—This is the *iron pyrites* of mineralogists, and exists in abundance in the earth. It occurs in cubes or some allied form, has a yellow color, metallic lustre, and a density of 4.98; and is so hard that it strikes fire with steel. Some varieties have a white color; but these usually contain arsenic. Others occur in rounded nodules, have a radiated structure divergent from a common centre, are often found in beds of clay, and are much disposed by the influence of air and moisture to yield sulphate of oxide of iron; these are suspected by Berzelius to be compounds of protosulphuret and bisulphuret of iron.

Bisulphuret of iron is not attacked by any of the acids except the nitric, and its best solvent is the nitro-hydrochloric acid. Heated in close vessels it gives off nearly half its sulphur, and is converted into magnetic iron pyrites. By heat and air together, it yields peroxide of iron.

This substance is much used instead of sulphur in the manufacture of sulphuric acid (492), and for obtaining the sulphur.

673. *Magnetic Iron Pyrites.*—This is a natural product, termed magnetic pyrites from being attracted by the magnet, and was formerly regarded as protosulphuret of iron; but its elements are in such a ratio, that it may be regarded as a compound of bisulphuret and protosulphuret. It is formed by heating the bisulphuret to redness in close vessels, by fusing iron filings with half their weight of sulphur, or by rubbing sulphur upon a rod of iron heated to whiteness. It is soluble in dilute sulphuric acid, yielding hydrosulphuric acid gas and a residue of sulphur.

It is almost always used in the preparation of hydrosulphuric acid gas.

IRON AND CARBON.

674. *Carburets of Iron.*—Carbon and iron unite in various proportions, but there are three compounds very distinct from each other—namely, graphite, cast or pig-iron, and steel.

Graphite, also known under the name of *plumbago* and *black lead*, occurs not unfrequently as a mineral production. It may be made artificially, by exposing iron, with excess of charcoal, to a violent and long-continued heat; and it is commonly generated in small quantity during the preparation of cast-iron. Pure specimens contain about four or five per cent. of iron, but sometimes its quantity amounts to ten per cent. Most chemists believe the iron to be chemically united with the charcoal; but according to the researches of Karsten, of Berlin, native graphite is only a mechanical mixture of charcoal and iron, while artificial graphite is a real carburet.

Graphite is exceedingly unchangeable in the air, and like charcoal is attacked with difficulty by chemical reagents. It may be heated to any extent in close vessels without change: but if exposed at the same time to the air, its carbon is entirely consumed, and oxide of iron remains.

Some specimens on being consumed leave behind scarcely a trace of iron, confirming the opinion above expressed (448), that this is not a proper carburet of iron, but a peculiar form of carbon, usually containing a little iron, as an accidental impurity. In further confirmation of this view of the subject, it may be contended that the proportion of iron contained in it is so variable that it cannot be considered as combined chemically with the carbon.

It has an iron-grey color, metallic lustre, and granular texture; and it is soft and unctuous to the touch. Its chief use is in the manufacture of pencils and crucibles; and in burnishing iron to protect it from rust, and as the basis of a preparation for lubricating machinery.

675. Cast iron is the product of the process for extracting iron from its ores, and is commonly regarded as a real compound of iron and charcoal. It always contains impurities, such as charcoal, undecomposed ore, and earthy matters, which are often visible by mere inspection; and sometimes traces of chromium, manganese, sulphur, phosphorus, and arsenic are present. It fuses readily at 2786°, which is a full red heat, and in cooling, it acquires a crystaline granular texture. The quality of different specimens is by no means uniform; and in commerce, it is said three varieties are usually distinguished. These are No. 1, or *black cast iron*, No. 2, or *mottled cast iron*, and *white cast iron*. This difference appears to be owing to the mode of combination, rather than to a difference in the proportion of carbon; for the white variety may be converted

into the black by exposure to a strong heat and cooling slowly, and the black may be changed into the white by being heated and rapidly cooled.

Of these varieties, No. 1, or black cast iron, is the softest, and is therefore much the most used. It is malleable to some extent, and admits of being easily filed or turned. Its specific gravity is lower than that of the other varieties, and it is said to melt at a lower temperature.

No. 2, or mottled cast iron, is intermediate in its properties between the other two, and needs no separate description.

White cast iron is nearly as hard as steel, and usually possesses a lamellar structure. It of course cannot be filed, or turned, or bored, and cannot be applied to any very important purpose.

Means have recently been devised for changing cast iron into malleable iron without fusion, as described above (663); so that articles may first be cast in the usual manner, and afterwards, without injuring their form, be changed into tough or malleable iron.

676. *Steel* is by far the most important of the compounds of iron and carbon. This compound was known at a very early period, and was called *acies* by the Romans. It is said a manufactory of steel existed in Sweden as early as the year 1340.

An inferior kind of steel is made directly from the ore, and is therefore called *natural steel.* The ore called brown hematite answers for this purpose, but that called *spathic iron*, which is a carbonate of iron, is generally used. It has therefore been called *steel ore.* Steel made in this manner is used only for the coarsest manufactures, as ploughs, &c.

But the best steel is now prepared from iron by the process of *cementation*, which consists in filling a large furnace with alternate strata of bars of the purest malleable iron and powdered charcoal, closing every aperture, so as perfectly to exclude atmospheric air, and keeping the whole during several days at a red heat. By this treatment the iron gradually combines with from 1.3 to 1.75 per cent. of carbon, its texture is greatly changed, and its surface is blistered. This is the *blistered steel* of commerce. This process may be effected even though the carbon does not touch the iron, provided a little oxygen is present. Carbonic oxide (449) is first formed, which is decomposed by the iron, and half the carbon absorbed, the remainder being given off in the form of carbonic acid, which by its escape produces the blistering just noticed. The decomposition takes place, however, mostly at the surface, the carbon being transferred from particle to particle of the iron, until the whole assumes nearly a uniform consistency.

By breaking bars of blistered steel into small pieces and welding them together, the texture is rendered still more uniform, and it receives the name of *German* or *shear steel.*

In ductility and malleability it is far inferior to iron; but exceeds it greatly in hardness, sonorousness, and elasticity. Its texture is also more compact, and it is susceptible of a higher polish. It sustains a full red heat without fusing, and is, therefore, less fusible than cast iron; but it is much more so than malleable iron.

677. To form *cast steel,* the blistered steel, as taken from the cementing oven, is broken in pieces and melted in pots, and cast into small parallelopipedons. This requires a very great heat, and is of course very expensive; but the metal is thus rendered of uniform texture throughout, which improves it very much for many purposes. It will not bear now to be heated above a bright cherry-red, and can scarcely be welded.

Instruments made of iron are often covered with animal charcoal in a close box, and exposed for an hour to a red heat, by which the surface is converted into steel, which is called *case-hardening*. It has recently been discovered that the ferrocyanide of potassium applied to heated iron, even in the open air, produces the same effect, wherever it touches it, almost instantly.

The celebrated Indian steel called *wootz,* it has recently been determined, is a compound of steel, and a very small quantity of silicon and aluminum; to which circumstance it seems to owe its peculiarities. Steel has also been alloyed with minute quantities of silver, platinum, rhodium, palladium, and osmium, by which its hardness, and, in some cases, its toughness, are improved, and it is not improbable the compounds may yet become highly useful in the arts.

678. Steel is hardened by being heated and suddenly cooled. When the greatest hardness is required, it is obtained by heating the steel red-hot, and plunging it into cold water, which makes it very brittle. Various substances are used instead of water, as oils, the acids, tallow, or even cold air, or in some cases, the mere contact of other metals.

When steel is thus hardened, it will become soft again, if it be heated up to the first point and then left to cool slowly (580); but any intermediate hardness may be secured by heating the article to the degree that corresponds to it, and then allowing it to cool of itself. This is called *tempering*, and is usually judged of by the colors that appear on the surface of the steel as it is heated; thus, a straw color corresponding to 430° or 450°, denotes the proper temper for penknives, razors, &c.; and the first tinge of purple, corresponding to 510°, is adapted to other coarser cutting instruments. Sometimes an oil-bath or fusible metal is used, and the proper temperature is indicated by a thermometer, so that the workman is not under the necessity of examining every separate article.

IRON AND IODINE.

There are two compounds of iron and iodine, the proto and sesqui iodides.

	Iron.	*Iodine.*	*Equiv.*	*Symbols.*
Protiodide of iron	1 eq. +	1 eq.	154.3	FeI
Sesquiodide of iron	2 eq. +	3 eq.	434.9	Fe_2I_3

679. *Protiodide of Iron.*—Protiodide is formed by digesting iodine in water with iron wire or filings. Heat is evolved; and on evaporating the solution in contact with the air as little as possible, the iodide is obtained as a grey crystaline mass, which is very deliquescent, and is soluble in water and alcohol. It is used in medicine.

680. *Sesquiodide of Iron* is obtained by exposing a solution of the protiodide to the air, or by digesting iron wire with an excess of iodine, and gently evaporating. It is of an orange color, and may be sublimed.

Other binary compounds of iron are the bromides, fluorides, phosphurets, &c., none of which possess any particular interest.

ZINC—CADMIUM.

ZINC.

Symbol Zn; Equivalent 32.3.

681. THIS metal was first mentioned under the term *zinetum*, in the sixteenth century, by Paracelsus; but it was probably known at a much earlier period. In commerce it is often called *spelter*. It is obtained either from *calamine*, which is a native carbonate of zinc, or from the sulphuret called *zinc blende*. It is procured from the former by heating it with carbonaceous matters, and from the latter by a similar process, after the ore has been roasted to expel the sulphur and oxydize the metal. Its preparation affords an instance of what is called *distillation by descent*. The furnace or crucible for reducing the ore is closed above, and in its bottom is fixed an iron tube, the upper aperture of which is in the interior of the crucible, and its lower terminates just above a vessel of water. The vapor of zinc, together with all the gaseous products, passes through this tube, and the zinc is condensed. The first portions are commonly very impure, containing cadmium and arsenic, the period of their disengagement being indicated by what the workmen call the *brown blaze;* but when the *blue blaze* begins, that is, when the metallic vapor burns with a bluish white flame, the zinc is collected. As thus obtained, it is never quite pure: it frequently contains traces of charcoal, sulphur, cadmium, arsenic, lead, and copper; and iron is always present. It may be freed from these impurities by distillation,—by exposing it to a

white heat in an earthen retort, to which a receiver full of water is adapted; but the first portions, as liable to contain arsenic and cadmium, should be rejected.

It is owing to these foreign bodies, particularly iron, that common zinc dissolves so rapidly in dilute sulphuric acid (205).

682. Zinc has a strong metallic lustre, and a bluish-white color. Its texture is lamellated, and its density about 7. At low or high degrees of heat it is brittle; but at temperatures between 210° and 300°, it is both malleable and ductile, a property which enables zinc to be rolled or hammered into sheets of considerable thickness. Heated to 400° it again becomes exceedingly brittle, and may be reduced to powder in a mortar. Its malleability is considerably diminished by the impurities which the zinc of commerce contains. It fuses at 773°, and when slowly cooled crystalizes in four or six sided prisms. Exposed in close vessels to a white heat, it sublimes unchanged.

Zinc is considerably used in the arts, especially in combination with copper in the form of brass, of which it usually constitutes about one-fourth part. In the laboratory, metallic zinc is much used in the construction of galvanic instruments. It has also been proposed for constructing pipes for conveying water, for culinary vessels, &c.; but it is so readily acted upon by other substances, that it is of doubtful utility for these purposes. Rolled into thin sheets, it answers, in many cases, as a cheap and quite durable substitute for sheet iron or tin plate.

Recently it has been used for coating sheet iron — which is then called *galvanized iron* (205)—to protect it from oxydation. When thus used, a galvanic current is probably established between the metals, and the iron is preserved on the principle already explained.

ZINC AND OXYGEN.

There is but one well-determined oxide of zinc, the protoxide.

	Zinc.	*Oxygen.*	*Equiv.*	*Symbol.*
Protoxide	1 eq. +	1 eq.	40.3	ZnO

683. *Protoxide of Zinc.*—Zinc undergoes little change by the action of air and moisture. When fused in open vessels it absorbs oxygen, and forms the white oxide, called flowers of zinc. Heated to full redness in a covered crucible, it bursts into flame as soon as the cover is removed, and burns with a brilliant white light. The combustion ensues with such violence, that the oxide as it is formed is mechanically carried up into the air. The heat at which it begins to burn is estimated at 941°.

This oxide is also generated during the solution of zinc in dilute sulphuric or hydrochloric acid, and the acid may be readily expelled from it by heat. At common temperatures it is white, but when heated to low redness it assumes a yellow color, which gradually disappears on cooling. It is quite fixed in the fire. It is insoluble in water, and, therefore, does not affect the blue color of plants; but it is a strong salifiable base, forming regular salts with acids, most of which are colorless. It combines also with some of the alkalies.

In consequence of the peculiar appearance of this oxide, as it is formed by the combustion of the metal, it has been called *nihil, album, philosopher's wool, pompholix, flowers of zinc,* &c.

Oxide of zinc has sometimes been substituted for white lead in house-painting, and forms a more durable paint; but the white color is not so clear.

Oxide of zinc is easily recognized by being precipitated from its solution as a hydrate, by caustic potassa or ammonia, but is again completely dissolved by an excess of the precipitant.

ZINC AND CHLORINE.

	Zinc.	Chlorine.	Equiv.	Symbol.
Chloride of zinc	1 eq. +	1 eq.	67.72	ZnCl

684. *Chloride of Zinc.*—This compound is formed, with evolution of heat and light, when zinc filings are introduced into chlorine gas; and it is readily prepared by dissolving zinc in hydrochloric acid, evaporating to dryness, and heating the residue in a tube through which dry gas is transmitted. It is colorless, fusible at a heat a little above 212°, has a soft consistence at common temperatures, hence called *butter of zinc*, sublimes at a red heat, and deliquesces in the air.

Mixed with hydrochlorate of ammonia in solution, it forms an excellent article for tinning copper, iron, &c. The two substances, in all probability, form a double salt.

Zinc forms definite compounds with iodine, bromine, fluorine, phosphorus, sulphur, &c.

CADMIUM.

Symbol Cd; Equivalent 55.8.

685. This metal has received its name from the circumstance that is generally, if not always, associated with zinc, some of the ores of which, particularly calamine, were formerly called *cadmeia.* Cadmium was discovered by Stromeyer, in the year 1817; and it has since been found in the ores of zinc in different parts of the world. During the reduction of the zinc it is sublimed and is found mixed with other substances, as soot and oxide of zinc in the upper part of the furnace.

To obtain metallic cadmium, the ore in which it is contained is dissolved in dilute sulphuric or hydrochloric acid, and, after adding a portion of free acid, a current of hydrosulphuric acid gas is transmitted through the liquid, by which means the cadmium is precipitated as sulphuret, while the zinc continues in solution. The sulphuret of cadmium is then decomposed by nitric acid, and the solution evaporated to dryness. The dry nitrate is dissolved in water, and an excess of carbonate of ammonia added. The white carbonate of oxide of cadmium subsides, which, when heated to redness, yields a pure oxide. By mixing this oxide with charcoal, and exposing the mixture to a red heat, metallic cadmium is sublimed.

A very elegant process for separating zinc from cadmium was proposed by Wollaston. The solution of the mixed metals is put into a platinum capsule, and a piece of metallic zinc is placed in it. If cadmium is present, it is reduced, and adheres so tenaciously to the capsule, that it may be washed with water without danger of being lost. It may then be dissolved either by nitric or dilute hydrochloric acid.

687. Cadmium, in color and lustre, has a strong resemblance to tin, but is somewhat harder and more tenacious. It is very ductile and malleable. Its specific gravity is 8.60, before being hammered, and 8.69 afterwards. It melts at about the same temperature as tin, and is nearly as volatile as mercury, condensing like it into globules which have a metallic lustre. Its vapor has no odor.

Cadmium might be employed in the arts for many useful purposes, but hitherto it has been found only in very small quantities. Heated in the open air it absorbs oxygen, and is converted into a protoxide. It is readily dissolved by nitric acid, and is also acted upon by the sulphuric and hydrochloric.

Cadmium forms different compounds also with chlorine, iodine, sulphur, phosphorus, and probably other substances.

TIN.

Symbol Sn; Equivalent 57.9.

688. TIN has been known from the most remote antiquity, and was in common use in the time of Moses.* It is supposed the ancients obtained it chiefly from Cornwall, England, the mines of which now yield a large part, it is said, of the tin of commerce. It is found also in India, Germany, Chili, and Mexico; but it is a little singular that it has not yet been discovered in the United States, except, perhaps, a few small crystals of the oxide in Chesterfield, Massachusetts, and a small vein of the ore in the White Mountains, in New Hampshire. The chief ores are the oxide and sulphuret.

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* Numbers xxxi, 22.

The tin of commerce is distinguished into two varieties, called *block* and *grain tin*, both of which are procured from the native oxide by means of heat and charcoal. In Cornwall, which has been celebrated for its tin mines during many centuries, the ore is both extracted from veins, and found in the form of rounded grains among beds of rolled materials, which have been deposited by the action of water. These grains, commonly called *stream tin*, contain a very pure oxide, and yield the purest kind of grain tin. An inferior sort is prepared by heating bars of tin, extracted from the common ore, to very near their point of fusion, when the more fusible parts, which are the purest, flow out; and the less fusible portions constitute block tin. The usual impurities are iron, copper, and arsenic.

689. Tin has a white color, and a lustre resembling that of silver. The brilliancy of its surface is but very slowly impaired by exposure to the atmosphere, nor is it oxydized even by the combined agency of air and moisture. Its malleability is very considerable; for the thickness of common tin-foil does not exceed $\frac{1}{1000}$ of an inch. In ductility and tenacity it is inferior to several metals. It is soft and inelastic, and when bent backwards and forwards, emits a peculiar crackling noise. Its specific gravity is about 7.3. At 442° it fuses, and if exposed at the same time to the air, its surface tarnishes, and a grey powder is formed. When heated to whiteness, it takes fire and burns with a white flame, being converted into peroxide of tin.

The uses of metallic tin are so numerous and so well known, that it is not necessary to enumerate them. It is probably most familiar to us, as it is used to coat sheet iron and copper, to protect them from the action of the atmosphere and moisture, forming what is usually called tin plate; and combined with antimony and copper to form Brittania metal.

TIN AND OXYGEN.

There are three oxides of tin, the protoxide, sesquioxide, and bin or peroxide.

	Tin.		*Oxygen.*	*Equiv.*	*Symbols.*
Protoxide	1 eq.	+	1 eq.	65.9	SnO
Sesquioxide	2 eq.	+	3 eq.	129.8	Sn_2O_3
Peroxide	1 eq.	+	2 eq.	73.9	SnO_2

690. *Protoxide of Tin.*—When chloride of tin in solution (692) is mixed with an alkaline carbonate, hydrated oxide of tin falls, which may be obtained as such in a dry form by washing with warm water, and drying at a heat not above 190°, with the least possible exposure to the air. The best mode of obtaining the anhydrous oxide is by heating the hydrate to redness in a tube from which air is excluded by a cur-

rent of carbonic acid gas. The same oxide is formed when tin is kept for some time fused in an open vessel.

Protoxide of tin has a specific gravity of 6.67. At common temperatures it is permanent in the air, but if touched by a red-hot body, it takes fire and is converted into the peroxide. Its salts are remarkably prone to absorb oxygen, both from the air and from compounds which yield oxygen readily. Thus it converts peroxide of iron into protoxide, and throws down mercury, silver, and platinum in the metallic state from their salts. With a solution of gold it causes a purple precipitate, the *purple of Cassius,* which appears to be a compound of the peroxide of tin and protoxide of gold. By this character protoxide of tin is recognized with certainty.

Sesquioxide of Tin.—This oxide is soluble in hydrochloric acid, and strikes with gold the *purple of Cassius,* like the protoxide, but is readily distinguished from it by being soluble in ammonia.

691. *Peroxide of Tin, Stannic Acid.*—This compound is most conveniently prepared by the action of nitric acid on metallic tin. Nitric acid, in its most concentrated state, does not act easily upon tin; but when a small quantity of water is added, violent effervescence takes place, owing to the evolution of nitrous acid and binoxide of nitrogen, and a white powder, the hydrated peroxide, is produced. On edulcorating this substance, and heating it to redness, watery vapor is expelled, and the pure peroxide, of a straw-yellow color, remains.

Binoxide of tin has very little disposition in any state to unite with acids, and, when dissolved by them, is very apt to separate itself spontaneously as a gelatinous hydrate. It acts the part of a feeble acid: it reddens litmus when its hydrate moistened is laid upon it, and it unites with the pure alkalies, forming soluble compounds which are called *stannates.*

The same compound apparently is obtained by decomposing perchloride of tin (693) by an alkali; but, as prepared by this process, it is soluble in dilute nitric and sulphuric acids, and in hydrochloric acid. These two varieties of this oxide may be transformed into each other, and are probably isomeric (342) compounds.

Melted with glass, this oxide forms a white enamel, and combined with a little oxide of lead, it is used as a polishing powder called *putty of tin.* To form it, an alloy of tin and lead is calcined in a reverberatory furnace.

TIN AND CHLORINE.

There are two chlorides of tin, the composition of which is as follows:

	Tin.	*Chlorine.*	*Equiv.*	*Symbols.*
Protochloride	1 eq. +	1 eq.	93.32	$SnCl$
Bichloride	1 eq. +	2 eq.	128.74	$SnCl_2$

692. *Protochloride of Tin.*—This compound is obtained by transmitting hydrochloric acid gas over metallic tin heated in a glass tube, when hydrogen gas is evolved, and the protochloride is obtained in the form of a grey solid.

A solution of protochloride of tin is obtained by heating granulated tin in strong hydrochloric acid as long as hydrogen gas continues to be evolved. This solution is much employed as a deoxydizing agent, being more powerful than the sulphate or nitrate of the protoxide; owing apparently to the tendency of the protochloride of tin to resolve itself into bichloride and metallic tin, the latter taking oxygen or chlorine from any metallic solutions which yield them readily.

The partially crystalized protochloride is sold under the name of *salt of tin*, and is much used as a mordant in dyeing.

693. *Bichloride of Tin.*—When protochloride of tin is heated in chlorine gas, or on distilling a mixture of 8 parts of granulated tin with 24 of bichloride of mercury, a very volatile, colorless liquid passes over, which is bichloride of tin. In an open vessel it emits dense white fumes, caused by the moisture of the air, and hence it was called the *fuming liquor* of Libavius, who discovered it. At 248° it boils, and the specific gravity of its vapor is found to be 9.12. With one-third of its weight of water it forms a solid hydrate, and in a larger quantity of water dissolves.

The solution of bichloride of tin, commonly called *permuriate of tin*, is much used in dyeing, and is prepared by dissolving tin in nitro-hydrochloric acid. The process requires care; for if the action be very rapid, as is sure to happen if strong acid be employed and much tin added at once, the peroxide will be spontaneously deposited as a bulky hydrate, and be subsequently redissolved with great difficulty. But the operation will rarely fail if the acid is made with two measures of hydrochloric acid, one of nitric acid, and one of water, and if the tin is gradually dissolved, one portion disappearing before another is added. The most certain mode of preparation, however, is to prepare a solution of the protochloride, and convert it into the bichloride, either by chlorine, or by gentle heat and nitric acid.

There are two sulphurets of tin, the protosulphuret and the bisulphuret. The bisulphuret possesses a beautiful yellow color and metallic lustre, and has therefore been called *aurum musivum* or *mosaic gold*. It is used in painting in imitation of bronze, and also for spreading upon the rubbers of electrical machines, instead of amalgam of zinc or tin.

Tin forms compounds also with iodine, bromine, phosphorus, and selenium

COBALT.

Symbol Co; Equivalent 29.5.

694. This metal is met with in the earth chiefly in combination with arsenic, constituting an ore from which all the cobalt of commerce is derived. It is a constant ingredient of meteoric iron, though in very small quantity. Its name is derived from the term *Kobold, an evil spirit*, applied to it by the German miners at a time when they were ignorant of its value, and considered it unfavorable to the presence of valuable metals.

When native arseniuret of cobalt is broken into small pieces, and exposed in a reverberatory furnace to the united action of heat and air, its elements are oxydized, most of the arsenious acid is expelled in the form of vapor, and an impure oxide of cobalt, called *zaffre*, remains.

From this substance metallic cobalt may be obtained by heating it with charcoal, or passing over it when heated to redness in a porcelain tube, a current of hydrogen gas.

695. Cobalt is a brittle metal, of a reddish grey color, and weak metallic lustre. Its density is believed to be about 8.5. It fuses at a heat rather lower than iron, and when slowly cooled it crystalizes. As usually prepared, it is atttracted by the magnet, and is susceptible of being rendered permanently magnetic; but it is believed this property does not belong to it when perfectly pure. It undergoes little change in the air, but absorbs oxygen when heated in open vessels. It is attacked with difficulty by sulphuric or hydrochloric acid, but is readily oxydized by means of nitric acid.

COBALT AND OXYGEN.

The two oxides of cobalt are composed as follows:

	Cobalt.	*Oxygen.*	*Equiv.*	*Symbols.*
Protoxide	1 eq. +	1 eq.	37.5	CoO
Sesquioxide	2 eq. +	3 eq.	83	Co_2O_3

696. *Protoxide of Cobalt.*—This oxide is of an ash-grey color, and is the basis of the salts of cobalt, most of which are of a pink hue. When heated to redness in open vessels, it absorbs oxygen, and is converted into the sesquioxide. It may be prepared by decomposing carbonate of the protoxide by heat in a vessel from which atmospheric air is excluded. It is easily recognized by giving a blue tint to borax when melted with it; and is employed in the arts, in the form of *smalt*, for communicating a similar color to glass, earthenware, and porcelain.

The smalt of commerce is prepared by fusing a mixture of zaffre, potassa, and sand, and reducing the mass to a moderately fine powder.

697. *Sesquioxide of Cobalt.*—This oxide may be readily formed, as before described, by heating the protoxide in the open air. It does not unite with any of the acids, and when strongly heated gives up a portion of its oxygen, and is reduced to a protoxide.

Another oxide analogous to the red oxide of manganese, containing 3 eq. of cobalt, and 4 eq. of oxygen, has been described.

COBALT AND CHLORINE.

	Cobalt.	*Chlorine.*	*Equiv.*	*Symbol.*
Chloride of cobalt	1 eq. +	1 eq.	64.92	CoCl

698. *Chloride of Cobalt.*—It is obtained in solution on dissolving metallic cobalt, its protoxide, or either of the other oxides in hydrochloric acid. It yields a pink-colored solution, and by evaporation, small crystals of the same color containing water of crystalization. When deprived of water its color is blue, a character on which is founded its use as a sympathetic ink; when letters are written with a dilute solution of the chloride, the color is so pale that it is invisible in the cold; but on heating gently, the letters appear of a blue color, and disappear as soon as the chloride has recovered its moisture from the atmosphere.

Different opinions have been entertained concerning the cause of these changes of color, which are so readily occasioned by slight changes of temperature; but the following explanation is probably correct. The solution is to be considered as hydrochlorate of cobalt, the color of which is pink, especially when considerably diluted, but is so faint that writing done with it is quite invisible. By exposing this to a gentle heat, oxygen and hydrogen (in the form of water) are expelled, and the blue chloride of cobalt is formed upon the surface of the paper, which, however, as the paper cools, is again, by the absorption of moisture, converted into the invisible hydrochlorate, as before.

This solution is called *Hellot's Sympathetic Ink.* If a little sulphate of iron is added, the color of the writing when warm appears of a greenish hue, but in time becomes permanently yellow.

There are several sulphurets of cobalt, but little is known of the compounds it forms with other bodies.

NICKEL.

Symbol Ni; Equivalent 29.5.

699. Nickel is a constituent of meteoric iron (661); but its principal ore is the copper-colored mineral of Westphalia, termed *kupfer-nickel, copper nickel; nickel* being an epithet of detraction, applied by the older German miners, because the mineral looked like an ore of copper, and yet they could extract none from it. The preparations of nickel may either be made from copper nickel, which is an arseniuret of nickel containing small quantities of sulphur, copper, cobalt, and iron, or from the artificial arseniuret called *speiss*, a metallurgic production obtained in forming smalt from the roasted ores of cobalt.

Some ten or twelve different processes have been devised for obtaining pure metallic nickel, but all of them are quite complicated.

700. Nickel has a strong metallic lustre, and is both ductile and malleable. When pure its color is white, intermediate between that of tin and silver, but the nickel of commerce is usually of a reddish color.

It is attracted by the magnet, and like iron may be rendered magnetic. Its specific gravity after fusion is about 8.28, but is increased to near 9.0 by hammering.

Nickel is very infusible, but less so than pure iron. It suffers no change at common temperatures by exposure to air and moisture; but it absorbs oxygen at a red heat, though not rapidly, and is partially oxydized. It decomposes water at the same temperature. Hydrochloric and sulphuric acids act upon it with difficulty; but by nitric acid it is readily oxydized, and forms a nitrate of the protoxide of nickel.

Nickel is scarcely used in the arts except in combination with other metals, as we shall hereafter see.

Oxygen, chlorine, sulphur, &c., form various compounds with nickel, which will be found described in other works.

SECTION VI.

METALS WHICH DO NOT DECOMPOSE WATER AT ANY TEMPERATURE, AND THE OXIDES OF WHICH ARE NOT REDUCED TO THE METALLIC STATE BY THE MERE ACTION OF HEAT.

ARSENIC.

Symbol As; Equivalent 37.7.

701. METALLIC arsenic sometimes occurs native, but more frequently it is found in combination with other metals, and especially with cobalt and iron. On roasting these arsenical ores in a reverberatory furnace, the arsenic, from its volatility, is expelled, combines with oxygen as it rises, and condenses into thick cakes on the roof of the chimney. The sublimed mass, after being purified by a second sublimation, is the virulent poison known by the name of *arsenic*, or *white oxide of arsenic*. From this substance the metal itself is procured by heating it with charcoal. The most convenient process is to mix the white oxide with about twice its weight of black flux (583), and expose the mixture to a red heat in a Hessian crucible, over which is luted an empty crucible for receiving the metal. The reduction is easily effected, and metallic arsenic collects in the upper crucible, which should be kept cool for the purpose of condensing the vapor. Most of the arsenic of commerce is obtained in the process of reducing the ores of cobalt (694) and nickel above described.

702. Arsenic is an exceedingly brittle metal: its structure is crystaline, and when slowly sublimed it is said to crystalize in rhombohedrons. Its specific gravity is 5.88. When heated to 356°, it sublimes without previously liquefying; for its point of fusion is far above that of its sublimation, and has not hitherto been determined. Its vapor has a strong odor of garlic, a property which affords a distinguishing character for metallic arsenic, as it is not possessed by any other metal, with the exception perhaps of zinc, which is said to emit a similar odor

when thrown in powder on burning charcoal. In close vessels it may be sublimed without change; but if atmospheric air be admitted, it is rapidly converted into the white oxide.

In general, the metal speedily tarnishes on exposure to the air and moisture, acquiring on its surface a dark film, and frequently it is oxydized quite through the mass. The product of this spontaneous oxydation, which is often sold in commerce under the name of *fly-powder*, or the exceedingly improper name of *cobalt*, is supposed by some to be a distinct oxide, but by others it is regarded as a mixture of the metal with the white oxide, to be hereafter described. Occasionally, the metal is quite permanent in the open air.

ARSENIC AND OXYGEN.

There are but two well determined compounds of arsenic and oxygen, both of which possess acid properties.

	Arsenic. - *Oxygen.*	*Equiv.*	*Symbols.*
Arsenious acid	2 eq. + 3 eq.	99.4	As_2O_3
Arsenic acid	2 eq. + 5 eq.	115.4	As_2O_5

703. ***Arsenious Acid.***—This compound, frequently called *white arsenic*, and *white oxide of arsenic*, is always generated when arsenic is heated in open vessels, and may be prepared by digesting the metal in dilute nitric acid. The white arsenic of commerce is derived from the native arseniurets of cobalt, being sublimed during the roasting of these ores for the preparation of zaffre, and it is purified by a second sublimation in iron vessels.

It is usually sold in a state of fine white powder; but when first sublimed, it is in the form of brittle masses, more or less transparent, colorless, of a vitreous lustre, and conchoidal fracture. This glass, which may also be obtained by fusion, gradually becomes opaque without undergoing any apparent change of constitution, either with respect to water or any other substance; but the change is certainly promoted by exposure to the atmosphere. Its sp. gravity is 3.7. At 380° it is volatilized, yielding vapors which do not possess the odor of garlic, and which condense unchanged on cold surfaces.

The taste of arsenious acid is stated differently by different persons. It is generally supposed to be acrid, but this is probably owing to the local inflammation by which such an experiment is apt to be followed.

It reddens vegetable blue colors feebly, an effect which is best shown by placing the acid in powder on moistened litmus paper. It combines with salifiable bases, forming salts which are termed *arsenites*.

The opaque variety is more soluble than the transparent; 1000 parts of water, at the ordinary temperature of the air, in one instance, taking up in 36 hours 12.5 parts of the former and only 9.6 of the latter. The same quantity of boiling water has been found to dissolve 115 parts of the opaque variety, and retain 29 on cooling, while of the transparent only 97 parts were dissolved, and 18 retained when cold.

This substance is dimorphous (362), which probably sufficiently accounts for there being two varieties of it. Usually it crystalizes in six-sided scales derived from a rhombic prism; but by slow sublimation it may be obtained in octohedral crystals which are perfectly transparent. Dissolved in hydrochloric acid, it also crystalizes from the solution in octohedrons.

704. This compound of arsenic is one of the most virulent poisons known, and acts not only when taken into the stomach, but also when applied externally to a wound, or inspired as a vapor. More or less local inflammation always takes place in the parts immediately acted upon, but it is generally believed by physicians that the deleterious effects result chiefly from its constitutional operation.

705. The symptoms vary with the quantity taken and the constitution of the sufferer. The earliest and most common are, a peculiar nauseous metallic taste in the mouth, with sickness at the stomach, and vomiting; but to this there are some exceptions. In cases rapidly fatal, extreme faintness, cold sweats, and slight convulsions, are observed at once; and instances have been known in which death has taken place without any pain or other prominent symptoms. If life is prolonged many hours, burning heat and extreme pain are felt in the stomach and intestines, attended by insatiable thirst; the pulse becomes very small, and the countenance puts on an anxious appearance, the skin appears livid, and is sometimes affected with eruptions. The recovery of those who survive is usually very slow.

706. It is not to be expected that remedial agents can be used to much advantage, in cases of poisoning with a substance so rapid and violent in its action upon the system as this; but it has recently been discovered that the hydrate of the sesquioxide of iron, operates as a powerful antidote, if promptly administered. Its remedial effect is founded on a very remarkable reaction. When hydrated peroxide of iron in a thin paste is mixed with solution of arsenious acid, the arsenious is converted into arsenic acid, and the peroxide of iron into the protoxide, which unite to form an inert arseniate of the protoxide of iron. Thus, $2Fe_2O_3$ and $As_2O_3 = 4\,FeO_1 + As_2O_5$. This hydrate of iron may be formed by dissolving iron in nitro-hydrochloric acid, and precipitating with a slight excess of ammonia. The hydrate should be well washed and preserved in close vials, in its *moist, pulpy state*, which is essential to its proper action. The dose should not be less than ten or twelve times the weight of the poison that has been taken.

The frequent exhibition of arsenious acid as a poison renders the detection of this compound an object of great importance to medical practitioners as well as to the chemist; and indeed it is a subject in which every individual has a fearful interest.

In this, as in all similar inquiries, the object to be held in view is the discovery of a few decisive characters, by means of which the poison may be distinguished from all other bodies; and when present but in small quantity, either in pure water, or in any fluids likely to be met with in the stomach, may with certainty be detected.

Some ten or twelve different tests have been proposed, some of which, however, it is admitted, are very uncertain in their indications, and they will therefore be entirely omitted. The following are several of the most important; and it is believed they are entirely sufficient, at least when taken in connection with each other. A single test should never be relied on; but several separate and independent trials should always be made.

707. 1. Ammoniacal nitrate of silver forms with arsenious acid a yellow precipitate, by which it can in many cases be readily detected. This preparation is made by dropping ammonia into a strong solution of nitrate of silver, until the precipitate at first formed is *nearly* all dissolved. The presence of an alkali, as ammonia, is essential, as without it the nitrate of silver will not be decomposed to form the arsenite of silver; and by the method proposed precisely the proper quantity of ammonia will be used.

This test would be sufficient if the suspected liquid were always a pure solution of arsenious acid; but the result is liable to be affected by a variety of other substances which may be present; as phosphoric acid, common salt, &c., and cannot, therefore, be fully relied on.

The precipitate thrown down by this reagent is soluble both in acids and in ammonia.

2. Ammoniacal sulphate of copper, which is made by adding ammonia to a solution of sulphate of oxide of copper until the precipitate at first thrown down is nearly all redissolved, occasions with arsenious acid a green precipitate, which has been long used as a pigment under the name of *Scheele's green.* This test, though well adapted for detecting arsenious acid dissolved in pure water, is very fallacious when applied to mixed fluids. Christison has proved that ammoniacal sulphate of copper produces in some animal and vegetable infusions, containing no arsenic, a greenish precipitate, which may be mistaken for Scheele's green; whereas, in other mixed fluids, such as tea and porter, to which arsenic has been previously added, it occasions none at all, if the arsenious acid is in small quantity. In some of these liquids, a free vegetable acid is doubtless the solvent, but arsenite of oxide of copper is also dissolved by tannin, and perhaps by other vegetable as well as some animal principles.

3. A current of hydrosulphuric acid gas passed through a solution containing arsenious acid, immediately produces a yellow color, by the formation of orpiment, the sesquisulphuret of arsenic. The precipitate is at first partially suspended in the liquid; but as soon as free hydrosulphuric acid is expelled by heating the solution, it subsides perfectly, and may easily be collected on a filter. One condition, however, must be observed in order to insure success, namely, that the liquid does not contain a free alkali; for sulphuret of arsenic is dissolved with remarkable facility by pure potassa or ammonia. To avoid this fallacy, it is necessary to acidulate the solution with a little acetic or hydrochloric acid.

But it does not necessarily follow, because hydrosulphuric acid causes a yellow precipitate, that arsenic is present; since there are not less than four other substances, namely, selenium, cadmium, tin, and antimony, the sulphurets of which, judging from their color alone, might possibly be mistaken for orpiment.

But by drying the precipitate and subjecting it to the process for obtaining metallic arsenic, to be hereafter described, the sulphuret of arsenic may readily be distinguished from these and all other substances. In the same manner, the precipitates obtained by the preceding tests should be examined.

4. But the most decisive test is to obtain the metallic arsenic, which may be done from the precipitates thrown down by the preceding tests; but, if the suspected substance is in the solid state, it may be at once subjected to this process.

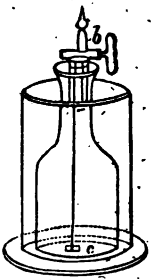
The substance supposed to contain the arsenious acid should be dried at a low temperature, and mixed with two or three times its own weight of black flux, and introduced carefully into the bottom of a small test glass, made by closing hermetically one end of a small glass tube some four or six inches in length. After wiping clean the inside of the tube by a piece of cotton attached to a wire, the part containing the mixture is to be held in the flame of a spirit-lamp, when the metallic arsenic will be sublimed and make its appearance in a beautiful ring of a steel-grey color and metallic lustre around the inside of the tube just above the part heated to redness. If the closed end of the tube be now cut off and heat again applied to the part containing the metallic crust, the metal will disappear and another ring of white oxide form a little higher up in the tube. A current of air will pass through the tube by which the metal will be oxydized, and carried a little higher up in the tube, where it will be condensed by the cool surface of the glass.

The occurrence of the precipitates by the first three tests, as described above, may be considered only as indirect indications of the presence of arsenic, which, as has been intimated, may all be fallacious; but the appearance of the metal itself, and the conversion of it again into the white oxide, must be considered as absolutely demonstrative of the fact.

5. Another curious test has been proposed by Marsh, which is founded on the well-known fact, that, when hydrogen in its nascent state comes in contact with any compound of oxygen and arsenic, the compound is decomposed, and the hydrogen and arsenic combine, producing a gaseous compound called arseniuretted hydrogen. If this gas is inflamed as it escapes into the air through a fine tube, it burns with the production of the vapor of water; while metallic arsenic or arsenious acid is deposited, according as the supply of oxygen is more or less abundant. Hence, if a piece of cold window-glass or white porcelain be held in the flame, its surface will instantly be covered with a thin coating of metallic arsenic; but if the flame be made to burn in the centre of a glass tube open at both extremities, the inner surface of the latter is covered in the course of half a minute with arsenious acid. If the tube be held obliquely, so that the flame shall strike against it, both depositions take place, and by applying the nostrils, the peculiar odor of arsenic is at once perceived.

708. The experiment is best made in the following manner. The suspected substance if it contains any solid matter is to be boiled a few minutes in distilled water and filtered, and then mixed with a few ounces of dilute sulphuric acid. It is then introduced into an apparatus constructed as follows: It consists of two parts, a cylindrical glass vessel *a*, Figure 83, and a capped bell glass furnished with a stopcock and tube *b*, through which the gas may issue. To the upper part of the bell-glass receiver a string is attached, by which a fragment of zinc *c* is suspended near the bottom of the vessel. Now by the action of the dilute acid upon the zinc, hydrogen gas is rapidly formed, and escapes by the stopcock and tube; or if the passage is closed, by accumulating in the bell-jar, it soon forces out the liquid so as to remove it from the zinc, and of course causes the action to cease. If the stopcock is opened the gas escapes through the tube by the pressure of the liquid, which again coming in contact with the zinc, the evolution of the gas at once recommences. On burning the gas as it escapes, the presence of arsenic will at once be recognised by the characters above specified.

Fig. 83.



An apparatus like the above answers well also for procuring pure hydrogen (377), or for the hydrogen lamp (382). It is, however, by no means essential for the perfect success of Marsh's experiment, though very convenient. For this, a four ounce vial answers well, with a cork and piece of pipe-stem for a tube, accurately fitted into the neck. After the materials are introduced and the cork inserted, care should always be taken to allow sufficient time to elapse for all the atmospheric air to escape before the gas is inflamed, or an explosion (380) may ensue.

But having by these means obtained the indication of arsenic above described, we are not to consider the test infallible, as it has been discovered that antimony is capable of forming with hydrogen a compound which burns much like arseniuretted hydrogen, and deposites a metallic crust on a cold surface in the same manner. The two gases may, however, be readily distinguished, for if the metallic crust is formed by arsenic, it will be volatilized by the application of heat, but if it be antimony, it will be melted and run together into a globule. If the part of the tube containing the crust be separated by a file and boiled a few minutes in pure water, it will disappear if the metallic deposit is arsenic, but will remain unaffected if it is antimony.

To avoid mistake, care should of course be taken to have all the materials used, perfectly pure, if possible; the water should be distilled, and the acid and zinc used should first be tested for arsenic. Not unfrequently, this substance is found in both the sulphuric acid and the zinc of commerce, which are therefore rendered unfit for use for this purpose. The apparatus, after being once used, should be thoroughly cleansed before being again employed.

In attempting to apply any of the preceding tests, inasmuch as the poison is never administered in a state of purity, we shall often be obliged to encounter difficulty at the outset, from the presence of other substances, particularly organic matter. The operator must often of course be guided by circumstances, but, in many cases, much foreign matter may be separated by evaporating to dryness *nearly*, and again dissolving in boiling water and filtering. The addition of a little acetic acid to coagulate any caseous or albuminous matter, will be beneficial, or the adoption of other means.

When a suspected substance is examined for arsenic, if the proper precautions are observed, the indications of the last two tests may be considered as decisive; and the two processes should always be carried on simultaneously. A single test, as above remarked, should rarely be relied upon in a case of so great importance; nor is it best to distract the attention by introducing too many.

Arsenious acid is considerably used in the arts, particularly in the manufacture of glass in imitation of porcelain and artificial gems, and in the preparation of Scheele's green. It is also used in medicine.*

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* A recent writer has proposed a very simple method to prevent those fata accidents that are often occurring by persons mistaking this substance for cream of tartar, or magnesia, or some similar substance. He proposes that one part of ferrocyanide of potassium, and one of sulphate of iron, both in fine powder, should be intimately mixed with every hundred parts of the arsenic, which can scarcely injure it for use in the arts. If a person should mistake it for some other substance, and attempt to dissolve it, the color of Prussian blue, at once making its appearance, would of course excite suspicion and lead to investigation, which would probably result in the discovery of the danger. The arsenic intended to be used in medicine, as the

709. *Arsenic Acid.*—This compound may be formed by dissolving one part of arsenious acid in six parts of concentrated nitric mixed with a little hydrochloric acid, and evaporating to perfect dryness.

This acid has a sour metallic taste, reddens vegetable blue colors, and with alkalies forms neutral salts, which are termed *arseniates*. It is much more soluble in water than arsenious acid, dissolving in five or six times its weight of cold, and in a still smaller quantity of hot water. It forms irregular grains when its solution is evaporated, but does not crystalize. If strongly heated, it fuses into a glass which is deliquescent. When exposed to a very strong red heat, it is resolved into oxygen and arsenious acid. It is an active poison.

ARSENIC AND HYDROGEN.

There is but one compound of arsenic and hydrogen, which is composed as follows:

	Arsenic.	*Hydrogen.*	*Equiv.*	*Symbol.*
Arseniuretted hydrogen	2 eq. +	3 eq.	78.4	As_2H_3

710. *Arseniuretted Hydrogen.*—This gas which was discovered by Scheele, besides the method described under the test of arsenious acid, may be formed by fusing metallic arsenic with its own weight of granulated zinc, and dissolving the alloy in strong hydrochloric acid.

The gas thus evolved is quite free from hydrogen, being absorbed without residue by a saturated solution of sulphate of oxide of copper. Its specific gravity, according to Dumas, is 2.69. It is colorless, and has a fetid odor, like that of garlic. It extinguishes bodies in combustion, but is itself kindled by them, and burns with a blue flame. It instantly destroys small animals that are immersed in it, and is poisonous to man in a high degree, having proved fatal to several experimenters. Water absorbs one-fifth of its volume, and acquires the odor of the gas. It wants altogether the properties of an acid.

ARSENIC AND SULPHUR.

There are three compounds of arsenic and sulphur, the proto, sesqui, and persulphuret.

	Arsenic.	*Sulphur.*	*Equiv.*	*Symbols*
Protosulphuret	1 eq. +	1 eq.	53.8	AsS
Sesquisulphuret	2 eq. +	3 eq.	123.7	As_2S_3
Persulphuret	2 eq. +	5 eq.	155.9	As_2S_5

711. *Protosulphuret of Arsenic.*—This is found native, constituting the *realgar* of commerce. It may be formed artificially by heating arsenious acid with about half its weight of sulphur, until the mixture is brought into a state of perfect fusion. The cooled mass is crystaline, transparent, and of a ruby red color, and may be sublimed in close vessels without change.

712. *Sesquisulphuret of Arsenic.*—*Orpiment*, or sesquisulphuret of arsenic is often found native, but it may also be prepared by fusing together

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presence of the substance would be objectionable, he proposes to scent with oil of lavender, by which it would always be distinguished from other substances of the kind.

With regard to this plan we may remark that it might succeed if all the arsenious acid in the world should pass through the hands of a single person who would attend to it, but as circumstances are, it is more than doubtful equal parts of arsenious acid and sulphur. A better mode, however, to obtain it quite pure is to transmit a current of hydrosulphuric acid gas through a solution of arsenious acid. Orpiment has a rich yellow color, fuses readily when heated, and becomes crystaline on cooling, and in close vessels may be sublimed without change. It is dissolved with great facility by the pure alkalies, and yields colorless solutions.

Orpiment is employed as a pigment, and is the coloring principle of the paint called *king's yellow.*

713. *Persulphuret of Arsenic* occurs only as an artificial production The sulphurets of arsenic are all poisonous.

Arsenic forms compounds also with chlorine, bromine, iodine, and phosphorus.

CHROMIUM.

Symbol Cr; Equivalent 28.

714. CHROMIUM was discovered in the year 1797, by Vauquelin, in a beautiful red mineral, the native dichromate of oxide of lead. It has since been detected in the mineral called *chromate of iron*, a compound of the oxides of chromium and iron, which occurs abundantly in several parts of this and other countries. It derives its name from χρωμα, *color*, in allusion to the variety and brilliancy of the colors of its compounds.

Metallic chromium may be obtained by exposing its oxide, mixed with charcoal, to the most intense heat of a smith's forge; but owing to its strong affinity for oxygen, the reduction is extremely difficult. Chromium has a white color, with a shade of yellow, and a distinct metallic lustre. It is a brittle metal, very fusible, and with difficulty attacked by acids, even by the nitro-hydrochloric. Its specific gravity is about 5.9. When fused with nitre, it is oxydized, and converted into chromic acid.

CHROMIUM AND OXYGEN.

There are but two compounds of these substances known, the sesquioxide and chromic acid.

	Chromium.	*Oxygen.*	*Equiv.*	*Symbols.*
Sesquioxide	2 eq. +	3 eq.	80	Cr_2O_3
Chromic acid	1 eq. +	3 eq.	52	CrO_3

715. *Sesquioxide of Chromium.*—This, the only known oxide of chromium, is prepared by dissolving chromate of potassa in water, and mixing it with a solution of nitrate of protoxide of mercury, when an orange-colored precipitate, chromate of that oxide, subsides. On heating this salt to redness in an earthen crucible, the mercury is dissipated in vapor, and the chromic acid is resolved into oxygen and oxide of chromium.

Oxide of chromium is of a green color, exceedingly infusible, and suffers no change by heat. It is insoluble in water, and after being strongly heated, resists the action of the most powerful acids. Fused with borax or vitreous substances, it communicates to them a beautiful green color, a property which affords an excellent test of its presence, and renders it exceedingly useful in the arts. The emerald owes its color to the presence of this oxide.

716. *Chromic Acid.*—This acid is best prepared by transmitting the gaseous fluoride of chromium into water contained in a vessel of silver or platinum, when by mutual decomposition of the gas and the water, hydrofluoric and chromic acids are generated; the former is then expelled by evaporating the solution to dryness, and the latter in a pure state remains.

By proper precautions this acid may be obtained in the form of acicular crystals of a cinnabar red color.

Pure dry chromic acid is black while warm, and of a dark red color when cold. It is very soluble in water, rendering it red or yellow, according to the degree of dilution;—when the solution is concentrated by heat and allowed to cool, it deposites red crystals, which deliquesce readily in the air. Its taste is sour, and with alkalies it acts as a strong acid. It is converted into the green oxide, with evolution of oxygen, by exposure to a strong heat. It destroys the color of indigo, and of most vegetable and animal coloring matters; a property advantageously employed in calico-printing, and which manifestly depends on the facility with which it is deprived of oxygen.

Chromic acid is characterized by its color, and by forming colored salts with alkaline bases.

The chlorides, bromides, iodides, fluorides, sulphurets, and phosphurets of chromium are omitted, as possessing nothing to render them of peculiar interest.

VANADIUM.

Symbol V; Equivalent 68.5.

717. **Vanadium**, so called from *Vanadis*, the name of a Scandinavian deity, was discovered in the year 1830 by Professor Sefström, of Fahlun, in iron prepared from the iron ore of Jaberg, in Sweden. Soon after Sefström's discovery, the same metal was found by Johnston, of Durham, in a mineral from Wanlockhead, in Scotland, where it occurs as a vanadiate of oxide of lead. A similar mineral, found at Zimapan, in Mexico, was examined in the year 1801, by Professor Del Rio, who, in the belief of having discovered a new metal, gave it the name of *Erythronium*, apparently from the red color of its acid; but as Collet Descotils, on being appealed to, declared the mineral to be chromate of lead, Del Rio abandoned his own opinion in deference to a higher authority. Thus have three persons noticed the existence of vanadium, without the knowledge of each other's labors.

This metal, in many of its properties, appears to be intermediate between chromium and uranium. It forms with oxygen two oxides and one acid, called *vanadic acid*,* and combines also with several other simple non-metallic elements.

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* An excellent writing ink, it is said, may be made from vanadiate of ammonia, and infusion of galls.—*Berzelius.*

MOLYBDENUM.

Symbol Mo; Equivalent 47.7.

718. THIS is a white, brittle metal, and so very infusible that it has never yet been perfectly fused. It is separated from its ore, the native sulphuret, with considerable difficulty. Neither the metal or any of its compounds have ever yet, it is believed, been applied to any useful purpose. The name was formerly applied to all light, friable, mineral substances of a dark color and peculiar greasy feeling, as plumbago or black lead (448, 674), with which it was formerly confounded; but its color is decidedly blue, while that of plumbago is black, so that the practised eye will easily distinguish between them. The specific gravity of the pure metal is about 8.6.

Molybdenum combines with oxygen in three proportions, forming two oxides and an acid. It unites also with other elementary substances, as chlorine, sulphur, &c.

TUNGSTEN.

Symbol W; Equivalent 99.7.

719. THIS metal derives its name from the Swedish words *Tung Sten, heavy stone*, from the density of its ores; it has also been called *wolfram*, from the mineral of that name, which is a tungstate of the oxides of iron and manganese.

The metal may without difficulty be obtained from this ore, but it requires a very intense heat to fuse it into a globule.

Native wolfram is found at Monroe and at Trumbull, in the state of Connecticut, as well as in several places in Europe.

Like molybdenum, this metal forms with oxygen two oxides and an acid. It forms definite compounds also with sulphur, chlorine, &c.

COLUMBIUM.

Symbol Ta; Equivalent 185.

720. THIS metal was discovered in 1801, by Hatchett, who detected it in a black mineral belonging to the British Museum, supposed to have come from Massachusetts, and from this circumstance applied to it the name of *columbium*. About two years after, Ekeberg, a Swedish chemist, extracted the same substance from *tantalite* and *yttro-tantalite;* and, on the supposition of its being different from columbium, described it under the name of *tantalum*. The identity of these metals, however, was established in the year 1809, by Wollaston.

This mineral has since been discovered at Haddam and Middletown, Connecticut; and there is some reason for supposing the first specimen was obtained from the same vicinity.

Columbium exists in most of its ores as an acid, united either with the oxides of iron and manganese, or with some of the earths. This acid is separated from the ore by fusing it with three or four times its weight of carbonate of potassa, and then decomposing the columbate of potassa that is formed, by an acid. By this process the columbic acid is precipitated as a white hydrate.

Columbic acid is with difficulty reduced to the metallic state by the action of heat and charcoal; but Berzelius succeeded in obtaining this metal by heating potassium with the double fluoride of potassium and columbium. On washing the reduced mass with hot water, in order to remove the fluoride of potassium, columbium is left in the form of a black powder. In this state it does not conduct electricity; but in a denser state it is a perfect conductor. By pressure it acquires metallic lustre, and has an iron-grey color. It is not fusible at the temperature at which glass is fused.

Several compounds of columbium with the non-metallic elements are known, but no application of any of them has been made in the arts.

This metal is still called tantalum in some parts of Europe, whence its symbol.

ANTIMONY.

Symbol Sb; Equivalent 64.6.

721. Antimony was first made known as a metal in the 15th century, by Basil Valentine, and is said to derive its name (*antimoine, anti-monk*,) from having proved fatal to some monks, to whom it was given as a medicine. It sometimes occurs native; but its only ore which is abundant, and from which the antimony of commerce is derived, is the sulphuret. This ore, the ***stibium*** of the ancients, was long regarded as the metal itself, and was called *antimony*, or *crude antimony*; while the pure metal was termed the *regulus of antimony*.

Metallic antimony may be obtained either by heating the native sulphuret in a covered crucible, with half its weight of iron filings; or by mixing it with two-thirds of its weight of cream of tartar and one-third of nitre, and throwing the mixture, in small successive portions, into a red-hot crucible. By the first process the sulphur unites with iron, and in the second it is expelled in the form of sulphurous acid; while the fused antimony, which in both cases collects in the bottom of the crucible, may be drawn off and received in moulds. The antimony thus obtained is not absolutely pure; and, therefore, for chemical purposes, it should be procured by heating the oxide with an equal weight of cream of tartar.

722. Antimony is a brittle metal, of a white color, running into bluish-grey, and is possessed of considerable lustre. Its density is 6.7. At 810° it fuses, and on cooling acquires a highly lamellated texture, and sometimes yields crystals: like arsenic, but unlike most other metals, its primary form is a rhombohedron. It has the character of being a volatile metal; but Thenard found that it bears an intense white heat without subliming, provided atmospheric air be perfectly excluded, and no gaseous matters, such as carbonic acid or watery vapor, be disengaged during the process. Its surface does not tarnish

by exposure to a dry atmosphere, but if moisture is present, a dark substance is formed, which is by some regarded as a definite compound. Heated to a white or even full red heat in a covered crucible, and then suddenly exposed to the air, it inflames, and burns with a white light. During the combustion a white vapor rises, which condenses on cool surfaces, frequently in the form of small shining needles of silvery whiteness. These crystals were formerly called *argentine flowers of antimony.*

Antimony is so very brittle that no use can be made of it in a state of purity; but alloyed with other metals it is much used in the arts. A native alloy of nickel and antimony is found in Europe.

ANTIMONY AND OXYGEN.

Oxygen forms with antimony an oxide and two acids, the *antimonious* and *antimonic* acids. They are composed as follows:

	Antimony.	*Oxygen.*	*Equiv.*	*Symbols.*
Sesquioxide	2 eq. +	3 eq.	153.2	Sb_2O_3
Antimonious acid	2 eq. +	4 eq.	161.2	Sb_2O_4
Antimonic acid	2 eq. +	5 eq.	169.2	Sb_2O_5

723. *Sesquioxide of Antimony.*—This is the substance formerly called *powder of Algaroth.* It is the basis of the well-known medicinal preparation called *tartar emetic*, which is the tartrate of antimony and potassa.

Glass, liver, and crocus of antimony, are nothing more than indefinite mixtures of this oxide with the sulphuret of antimony. They are formed by roasting the native sulphuret till a portion of oxide is formed, and then vitrefying the mixture with a strong heat.

724. *Antimonious Acid.*—When metallic antimony is digested in strong nitric acid, the metal is oxydized at the expense of the acid, and hydrated antimonic acid is formed; and on exposing this substance to a red heat, it gives out water and oxygen gas, and is converted into antimonious acid. It is also generated when the oxide is exposed to heat in open vessels. Thus, on heating sulphuret of antimony with free exposure to the air, sulphurous acid and sesquioxide of antimony is generated; but on continuing the roasting until all the sulphur is burned, the oxide gradually absorbs oxygen and passes into antimonious acid. Antimonious acid is white while cold, but acquires a yellow tint when heated, is very infusible, and fixed in the fire, two characters by which it is readily distinguished from the oxide. It is insoluble in water, and likewise in acids, after being heated to redness It combines in definite proportions with alkalies, and its salts are called *antimonites.* Antimonious acid is precipitated from these salts by acids as a hydrate, which reddens litmus paper, and is dissolved by hydrochloric and tartaric acids, though without appearing to form with them definite compounds.

725. *Antimonic Acid.*—This acid, sometimes called *peroxide* of antimony, is obtained as a white hydrate, either by digesting the metal in strong nitric acid, or by dissolving it in nitro-hydrochloric acid, concentrating by heat to expel excess of acid, and throwing the solution into water. When recently precipitated it reddens litmus paper, and may then be dissolved in water by means of hydrochloric or tartaric acid. It does not enter into definite com-

binations with acids, but with alkalies forms salts, which are called *antimoniates*. When hydrated antimonic acid is exposed to a temperature of 500° or 600°, the water is evolved, and the anhydrous acid of a yellow color remains. In this state it resists the action of acids. When exposed to a red heat, it parts with oxygen, and is converted into antimonious acid.

ANTIMONY AND CHLORINE.

Antimony forms with chlorine three compounds, as follows:

	Antimony.	*Chlorine.*	*Equiv.*	*Symbols.*
Sesquichloride	2 eq.	+ 3 eq.	235.46	Sb_2Cl_3
Bichloride	2 eq.	+ 4 eq.	270.88	Sb_2Cl_4
Perchloride	2 eq.	+ 5 eq.	306.3	Sb_2Cl_5

726. *Sesquichloride of Antimony.*—The sesquichloride of antimony is always formed when antimony in fine powder is dropped into a jar of chlorine gas. Spontaneous combustion takes place between them instantly upon their coming in contact. At common temperatures it is a soft solid, and has therefore been called *butter of antimony*. It is liquefied by a very gentle heat, and crystalizes on cooling.

727. The *bichloride* and *perchloride* of antimony possess no properties that render them of particular interest.

The native *sulphuret of antimony* is a sesquisulphuret. Its specific gravity is 4.62. When this is boiled in a solution of potassa or soda, a liquid is obtained, from which, on cooling, an orange-red matter is deposited, called *Kermes mineral*. On subsequently neutralizing the cold solution with an acid, the *golden sulphuret* of the pharmacopœia is obtained. These compounds now possess little interest.

728. *Antimoniuret of Hydrogen* is formed whenever hydrogen in its nascent state is brought in contact with this metal. The compound is gaseous, and is colorless and insoluble in water. It much resembles arseniuretted hydrogen; but the two compounds may easily be distinguished by means before pointed out (708).

URANIUM.

Symbol U; Equivalent 217.

729. This metal was discovered in 1789, by the German analyst, Klaproth, who named it after the new planet Uranus, the discovery of which took place in the same year. It was obtained from a mineral of Saxony, called, from its black color, *pitch-blende*, which consists of protoxide of uranium and oxide of iron.

From this ore the metal is extracted without difficulty; it is of a dark-grey color, is fused with difficulty, and has a specific gravity of 9.

With oxygen it unites in two proportions, the first of which, or protoxide, is used for painting black upon porcelain. The metal is known to combine also with chlorine and sulphur.

CERIUM.

Symbol Ce; Equivalent 46.

730. This metal, named after the planet Ceres, was discovered in 1803 in a rare Swedish mineral. It constitutes 34 per cent., as has since been determined, of the mineral called *Allanite*, in honor of its discoverer, Mr. Allan.

Cerium is a white, brittle metal, but its properties are little known. It forms two compounds with oxygen, and is capable of uniting also with chlorine and sulphur.

LANTHANUM.

Symbol La; Equivalent ?

731. Lanthanum is a new metal, recently discovered by Mosander, associated with cerium. It receives its name from *λανθανω*, *I lurk* or *elude*, in allusion to its having remained so long concealed in the ores of cerium. Little is known of its properties or compounds.

BISMUTH.

Symbol Bi; Equivalent 71.

732. This metal was known to the ancients, though often confounded by them with lead and tin; but it appears to have derived the name of *bismuth*, or more properly *wismuth*, from the German miners. It occurs in the earth both native and in combination with other substances, such as sulphur, oxygen, and arsenic. That which is employed in the arts, is derived chiefly from native bismuth, and commonly contains small quantities of sulphur, iron, and copper. It may be obtained pure for chemical purposes, by heating the oxide or subnitrate to redness, along with charcoal.

Bismuth has a reddish-white color and considerable lustre. Its structure is highly lamellated, and when slowly cooled, it crystalizes in octohedrons. Its density is about 9.8. It is brittle when cold, but may be hammered into plates while warm. At 476° it fuses, and sublimes in close vessels at a red heat. It is a less perfect conductor than most other metals.

Bismuth is used in the arts in combination with other metals, but never, it is believed, in its pure state.

It forms definite compounds with oxygen, chlorine, sulphur, and other non-metallic elementary substances.

TITANIUM.

Symbol Ti; Equivalent 24.3.

733. This metal was first recognized as a new substance by Mr. Gregor, and its existence was afterwards established by Klaproth, who fancifully gave it the name of *titanium*, after the *Titans* of ancient fable. But the properties of the metal were not ascertained in a satisfactory manner until the year 1822, when Wollaston was led to examine some minute crystals which were found in a slag, at the bottom of a smelting furnace, at the great iron works at Merthyr Tydvil, in Wales.

Gregor obtained it from a mineral called *menachanite*, which is found in the valley of Menachan, in Cornwall. Since that time, it has been discovered that the mineral called *rutile* is nearly pure *titanic acid*, and *anatase* is composed solely of the protoxide of titanium.

The metal possesses a beautiful copper red color, and is so exceedingly hard that it will scratch rock-crystal.

Oxide of titanium has recently been considerably used to color mineral teeth, in imitation of natural teeth, but the metal itself has not yet been applied to any useful purpose.

There are several compounds of chlorine, sulphur, &c., with titanium.

TELLURIUM.

Symbol Te; Equivalent 64.2.

734. Tellurium is a rare metal, hitherto found only in the gold mines of Transylvania, and even there in very small quantity. It was discovered in 1798, by Klaproth, who gave it the name of *tellurium*, from *tellus, the earth*, suggested by the source from which he drew the name of uranium. It occurs in the metallic state, chiefly in combination with gold and silver.

Tellurium has a tin-white color, running into lead-grey, a strong metallic lustre, and lamellated texture. It is very brittle, and its density is 6.14. It fuses at a temperature below redness, and at a red heat is volatile. When heated before the blowpipe it takes fire, burns rapidly with a blue flame bordered with green, and is dissipated in grey-colored, pungent, inodorous fumes.

It has been doubted by some whether this substance should not be classed with sulphur, selenium, &c., as a non-metallic element, rather than with the metals, where it is usually placed by English chemists. One reason given for refusing it a place among the metals, is the fact that it is dissolved in concentrated sulphuric acid without being oxydized, which is not the case with any acknowledged metal.

It is capable of uniting with oxygen, chlorine, sulphur, and hydrogen.

COPPER.

Symbol Cu; Equivalent 31.6.

735. Copper is one of the most abundant of the metals, and was well known to the ancients. Native copper is by no means uncommon, being found more or less in most copper

mines; it occurs in large amorphous masses in some parts of America,* and is sometimes met with in octohedral crystals, or in some of the forms allied to the octohedron.

This metal received its Latin name, *cuprum*, (from which the English name, copper, is derived,) from the circumstance that it was first discovered in the island of Cyprus, in the Mediterranean, or at least was first wrought there to any considerable extent.

The copper of commerce is extracted chiefly from the native sulphuret; especially from copper pyrites, a double sulphuret of iron and copper; but much is also obtained from the oxides. Carbonate, phosphate, silicate, sulphate, and other salts of copper, are found native.

The metal is extracted from the oxides and the native carbonate by simply heating them with charcoal in a wind furnace, but the sulphurets are reduced with much more difficulty.

736. Copper is distinguished from all other metals, titanium excepted, by having a red color. It receives a considerable lustre by polishing. Its density, when fused, is 8.9, and is increased by hammering. It is both ductile and malleable, and in tenacity is inferior only to iron. It is hard and elastic, and consequently, sonorous. Its point of fusion is 1996°, being less fusible than silver and more so than gold.

Copper undergoes little change in a perfectly dry atmosphere; but is rusted in a short time by exposure to air and moisture, being converted into a green substance, carbonate of the black oxide of copper. At a red heat it absorbs oxygen, and is converted into black scales of oxide. It is attacked with difficulty by hydrochloric and sulphuric acids, and not at all by solutions of the vegetable acids, if atmospheric air be excluded; but if air have free access, the metal absorbs oxygen with rapidity, the attraction of the acid for the oxide of copper co-operating with that of the copper for oxygen. Nitric acid acts with violence on copper, forming a nitrate of the black oxide.

ALLOYS OF COPPER.

737. Copper, in its separate state, is used extensively in the arts for various important purposes, and it also forms with several other metals many very useful alloys.

With tin, copper forms several valuable alloys, which are characterized by their sonorousness. *Bronze* is an alloy of copper with about eight or ten per cent. of tin, together with small quantities of other metals, which are not essential to the compound. Cannons are cast with an alloy of a similar kind.

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* Near the shore of Lake Superior, a mass of native copper was discovered in 1821, which was computed to weigh 2200 pounds.

The best *bell-metal* is composed of 80 parts of copper and 20 of tin;—the Indian gong, celebrated for the richness of its tones, contains copper and tin in this proportion. A specimen of English bell-metal was found by Thompson to consist of 80 parts of copper, 10.1 of tin, 5.6 of zinc, and 4.3 of lead. Lead and antimony, though in small quantity, have a remarkable effect in diminishing the elasticity and sonorousness of the compound. *Speculum-metal*, with which mirrors for telescopes are made, consists of about two parts of copper and one of tin. The whiteness of the alloy is improved by the addition of a little arsenic.

Copper and zinc unite in several proportions, forming alloys of great importance in the arts. The best *brass* consists of four parts of copper to one of zinc; and when the latter is in a greater proportion, compounds are generated which are called *tombac*, *Dutch gold*, and *pinchbeck*. The *white copper* of the Chinese is composed of 40.4 parts of copper, 25.4 of zinc, 31.6 of nickel, and 2.6 of iron.

738. The art of tinning copper consists in covering that metal with a thin layer of tin, in order to protect its surface from rusting. For this purpose, pieces of tin are placed upon a well-polished sheet of copper, which is heated sufficiently for fusing the tin. As soon as the tin liquefies, it is rubbed over the whole sheet of copper; and, if the process is skilfully conducted, adheres uniformly to its surface. The oxydation of the tin, a circumstance which would entirely prevent the success of the operation, is avoided by employing fragments of resin or muriate of ammonia, and regulating the temperature with great care. The two metals do not actually combine; but the adhesion is certainly owing to their mutual affinity. Iron, which has a weaker attraction than copper for tin, is tinned with more difficulty than that metal.

Antimony and copper form an important alloy with tin, called *Britannia metal*.

An alloy of copper with a tenth part of arsenic is so very similar in appearance to silver, that it is sometimes substituted for it.

German silver, which has been recently so much in use for various purposes, is an alloy of copper with nickel and zinc. The proportions, it is believed, are variable.

Equal parts of copper and zinc forms *hard solder*, which is used in soldering together pieces of brass.

COPPER AND OXYGEN.

It is generally believed there are three oxides of copper, hough some have enumerated only two. They are the di, roto, and bi or per oxides, which are composed as follows:

	Copper.	*Oxygen.*	*Equiv.*	*Symbols*
Dioxide	2 eq.	+ 1 eq.	71.2	Cu_2O
Protoxide	1 eq.	+ 1 eq.	39.6	CuO
Binoxide	1 eq.	+ 2 eq.	47.6	CuO_2

739. *Red, or Dioxide of Copper.*—This compound occurs native in the form of octohedral crystals, and is found of peculiar beauty in the mines of Cornwall. It may be prepared artificially by heating, in a covered crucible, a mixture of 31.6 parts of copper filings with 39.6 of the black oxide; or still better, by arranging thin copper plates one above the other, with interposed strata of the black oxide, and exposing them to a red heat carefully protected from the air. Another method is by boiling a solution of acetate of protoxide of copper with sugar, when the suboxide subsides as a red powder. Its specific gravity is 6.1.

This oxide is red only when pure; in the state of a hydrate its color is orange-yellow.

740. *Black Oxide.*—This compound, the *copper black* of mineralogists, is sometimes found native, being formed by the spontaneous oxydation of other ores of copper. It may be prepared artificially by calcining metallic copper, by precipitation from the salts of copper by means of pure potassa, and by heating nitrate of copper to redness. It varies in color from a dark brown to a bluish-black, according to the mode of formation, and its density is 6.4. It undergoes no change by heat alone, but is readily reduced to the metallic state by heat and combustible matter. It is insoluble in water, and does not affect the vegetable-blue colors. It combines with nearly all the acids, and most of its salts have a green or blue tint. It is soluble likewise in ammonia, forming with it a deep blue solution, a property by which protoxide of copper is distinguished from all other substances.

Copper is separated in the metallic state from the solution of its salts by a rod of iron or zinc. The copper thus obtained, after being digested in a dilute solution of hydrochloric acid, is almost chemically pure.

The best mode of detecting copper, when supposed to be present in mixed fluids, is by hydrosulphuric acid. The sulphuret, after being collected and heated to redness, in order to char organic matter, should be placed on a piece of porcelain, and digested in a few drops of nitric acid. Sulphate of protoxide of copper is formed, which, when evaporated to dryness, strikes the characteristic deep blue tint on the addition of ammonia.

741. *Binoxide of Copper.*—This oxide was prepared by Thenard, by the action of peroxide of hydrogen upon the black oxide just described.

CHLORINE AND COPPER.

There are two chlorides of copper, exactly corresponding in composition to the di and protoxides.

	Copper.	Chlorine.	Equiv.	Symbols.
Dichloride	2 eq.	+ 1 eq.	98,6	Cu^2Cl
Protochloride	1 eq.	+ 1 eq.	67	$CuCl$

742. *Dichloride of Copper.*—When copper filings are introduced into an atmosphere of chlorine gas, the metal takes fire spontaneously, and both the chlorides are generated. The *dichloride* may be conveniently prepared by heating copper filings with twice their weight of corrosive sublimate. It has been prepared in different ways, and called *resin of copper*, and *white muriate of copper*. It is slowly deposited in crystaline grains, when the green solution of chloride of copper is kept in a corked bottle, in contact with metallic copper.

It is insoluble in water, but dissolves in hydrochloric acid, and is precipitated unchanged by water as a white powder. Its color varies with the mode of preparation, being white, yellow, or dark brown. It is apt to absorb oxygen from the atmosphere, forming a green-colored compound of oxide and chloride of copper; a change to which the dichloride prepared in the moist way is peculiarly prone.

743. *Chloride of Copper.*—The chloride of copper is obtained in solution of a green color by dissolving protoxide of copper in hydrochloric acid, and crystalizes by due concentration in green needles, which are deliquescent and very soluble in alcohol. When heated, they fuse, lose water, and the anhydrous chloride, in form of a yellow powder, is left; but the heat must not exceed 400°, as beyond that degree the chloride loses half its chlorine, and is converted into the dichloride.

There are also several sulphurets, phosphurets, and other binary compounds of copper. The disulphuret is the *copper glance* of mineralogists, and the protosulphuret is a constituent of *copper pyrites*.

LEAD.

Symbol Pb; Equivalent 103.6.

744. This metal was well known to the ancients. As a native production it is very rare; but in combination with sulphur it occurs in great quantity.

Besides this there are no less than twenty-six other ores of this metal. All the lead of commerce, however, is extracted from the native sulphuret, the *galena* of mineralogists. This ore, in the state of coarse powder, is heated in a reverberatory furnace, with the occasional addition of quicklime, by which the sulphuric acid formed is immediately taken up. But the lead prepared in this way is seldom if ever quite pure, often containing a little copper or iron, and especially silver.

A small proportion of silver is almost always contained in the native sulphuret of lead; and sometimes is so abundant that the ore is worked for the silver it contains, rather than for the lead. In such cases, most of the lead is separated in the form of *litharge*, from (λιθος αργυρος.) (748).

745. Lead has a bluish-grey color, and when recently cut, a strong metallic lustre; but it soon tarnishes by exposure to the air, acquiring a very superficial coating, beyond which the action does not seem to extend. Its specific gravity is 11.38. It is soft, flexible, and inelastic. It is both malleable and ductile, possessing the former property in particular to a considerable extent. In tenacity, it is inferior to all ductile metals. It fuses at about 612°, and when slowly cooled forms octohedral crystals. It may be heated to whiteness in close vessels without subliming.

Lead absorbs oxygen quickly at high temperatures. When fused in open vessels, a grey film is formed upon its surface, which is a mixture of metallic lead and protoxide; and when strongly heated it is dissipated in fumes of the protoxide. In distilled water, previously boiled and preserved in close vessels, it undergoes no change; but in open vessels it is oxydized with considerable rapidity, yielding minute, shining, brilliantly white, crystaline scales of carbonate of the protoxide, the oxygen and the carbonic acid being derived from the air. The presence of saline matter in water retards the oxydation of the lead; and some salts, even in very minute quantity, prevent it altogether.

746. This protecting influence of some salts has long been known; but it is only within a very recent period, it has been determined that their preservative power is materially connected with the insolubility of the compound which the acid of the salt is capable of forming with lead. Thus, phosphates and sulphates, as well as chlorides and iodides, are highly preservative; so small a quantity as $\frac{1}{30000}$ part of phosphate of soda or iodide of potassium in distilled water preventing the corrosion of lead. In a preservative solution the metal gains weight during some weeks, in consequence of its surface gradually acquiring a superficial coating of carbonate, which is slowly deposited by the saline matter of the solution. The metallic surface being thus covered with an insoluble film, which adheres tenaciously, all further change ceases. Many kinds of spring-water, owing to the salts which they contain, do not corrode lead: and hence, though intended for drinking, it may be safely collected in leaden cisterns.

Lead is not attacked by the hydrochloric or the vegetable acids, though their presence, at least in some instances, accelerates the absorption of oxygen from the atmosphere in the same manner as with copper. Cold sulphuric acid does not act upon it; but when boiled in that liquid, the lead is slowly oxydized at the expense of the acid. The only proper solvent for lead is nitric acid. This reagent oxydizes it rapidly, and forms with its oxide a salt, which crystalizes in opaque octohedrons by evaporation.

ALLOYS OF LEAD.

747. Lead like copper forms with several other metals many very useful alloys.

Tin and lead unite readily when fused together, constituting solder, of which two kinds are distinguished. The alloy called *fine solder*, consists of two parts of tin and one of lead, fuses at about 360°, and is much employed in tinning copper. The *coarse solder* contains ¼ of tin, fuses at about 500°, and is the substance used for soldering by glaziers. Thus, by varying the relative quantity of the metals, a solder of different fusibility may be obtained. The process of hard soldering, or *brazing*, by which two surfaces of copper are cemented together, is done with *hard solder*, which is made by fusing together brass and zinc: the copper requires to be heated, when this solder is used, to near its point of fusion.

Most of the *alloys* of tin and lead, made in atomic proportion, have a specific gravity less than their calculated density; from which it is manifest that they expand in uniting. The *amalgams* (581) of lead and tin, on the contrary, occupy less space when combined than their elements did previously.

Tin alloyed with small quantities of antimony, copper, and bismuth, forms the best kind of pewter. Inferior sorts contain a large proportion of lead.

Tin, lead, and bismuth, form an alloy which is fused at a temperature below 212°. The best proportion is 8 parts of bismuth, 5 of lead, and 3 of tin.

An alloy of three parts of lead to one of antimony constitutes the substance of which types for printing are made.

Lead-shot is made of an alloy of lead and arsenic. The arsenic is added to facilitate the manufacture.

LEAD AND OXYGEN.

Oxygen forms with lead three compounds, besides the red oxide, which is composed of 2 equivalents of the protoxide and 1 eq. of the peroxide. Their composition will appear from the following table:

	Lead.	*Oxygen.*	*Equiv.*	*Symbols.*
Dinoxide	2 eq. +	1 eq.	215.2	Pb_2O
Protoxide	1 eq. +	1 eq.	111.6	PbO
Peroxide	1 eq. +	2 eq.	119.6	PbO_2
Red oxide	Protoxide 2 eq. Peroxide 1 eq.		342.8	

Dinoxide of lead is always an artificial production, and is incapable of combining with acids to form salts.

748. *Protoxide of Lead.*—This oxide is prepared on a large scale by collecting the grey film which forms on the surface of

melted lead, and exposing it to heat and air until it acquires a uniform yellow color. In this state it is the *massicot* of commerce; and when partially fused by heat, the term *litharge* (744) is applied to it. As thus procured, it is always mixed with the red oxide. It may be obtained pure by adding ammonia to a cold solution of nitrate of protoxide of lead until it is faintly alkaline, washing the precipitated subnitrate with cold water, and when dry, heating it to a moderate redness for an hour in a platinum crucible. An open fire should be used, and great care taken to prevent combustible matter in any form from contact with the oxide.

Protoxide of lead is red while hot, but has a rich lemon-yellow color when cold, is insoluble in water, fuses at a bright red heat, and is fixed and unchangeable in the fire. Its density is 9.42. The fused protoxide has a highly foliated texture, and is very tough, so as to be pulverized with difficulty.

749. This oxide combines readily with oils, and is therefore used by painters in the form of litharge, as a drier. Boiled with olive oil and a small quantity of water, it forms the *diachylon* of pharmacopœias, which is much used in medicine in the formation of various plasters. The elements of oil, it is supposed, undergo a change, and two acids are formed, the *oleic* and *margaric*, which combine with the oxide of lead, as will be explained in the third part of this work.

It is capable also of combining with some of the alkalies and earths, forming compounds which are more or less soluble. A body of this kind, formed by boiling lime and litharge together, is capable of crystalizing, and has been used for coloring the hair black. The sulphur contained in the hair combines with the lead, and forms in the substance of the hair the black sulphuret of lead, which serves as a coloring matter and is not liable to change.

The best method of detecting the presence of lead in wine or other suspected mixed fluids, is by means of hydrosulphuric acid. The sulphuret of lead, after being collected on a filter and washed, is to be digested in nitric acid diluted with twice its weight of water, until the dark color of the sulphuret disappears. The solution of the nitrate should then be brought to perfect dryness on a watch-glass, in order to expel the excess of nitric acid, and the residue be redissolved in a small quantity of cold water. On dropping a particle of iodide of potassium into a portion of this liquid, yellow iodide of lead will instantly appear.

Protoxide of lead unites readily with earthy substances, forming with them a transparent colorless glass. Owing to this property it is much employed for glazing earthenware and porcelain. It enters in large quantity into the composition of flint-glass, which it renders more fusible, transparent, and uniform.

Lead is separated from its salts in the metallic state by iron or zinc. The best way of demonstrating this fact is by dissolving 1 part of acetate of protoxide of lead in 24 of water, and suspending a piece of zinc in the solution by means of a thread. The lead is deposited upon the zinc in a peculiar arborescent form, giving rise to the appearance called *arbor Saturni.*

750. *Peroxide of Lead.*—This compound is always an artificial production. It is incapable of uniting as a peroxide with the acids, and by heat is converted into the protoxide.

When eight parts of this oxide are mixed with two and a half parts of pure dry tartaric acid in a dry capsule, ignition very soon takes place throughout the whole mass, which is very vivid, and of long duration. Other vegetable acids used in the same manner with this oxide, produce a similar effect.

751. *Red Oxide.*—This oxide, the *red lead,* or *minium* of commerce, is employed as a pigment, and in the manufacture of flint-glass. It is formed by oxydizing lead by heat and air without allowing it to fuse, and then exposing it in open vessels to a temperature of 600° or 700°, while a current of air plays upon its surface. It slowly absorbs oxygen, and is converted into minium.

This oxide does not unite with acids. When heated to redness it gives off pure oxygen gas, and is reconverted into the protoxide. When digested in nitric acid it is resolved into protoxide and peroxide of lead, the former of which unites with the acid, while the latter remains as an insoluble powder.

It is said that the deep red color can be produced only when large quantities are prepared at the same time.

752. *Chloride of lead* occurs as a natural production under the name of *horn lead* or *cerasite.* It may also be formed artificially.

753. *Iodide of lead,* which is always an artificial production, is distinguished for its beautiful yellow color.

The bromide, fluoride, sulphuret, phosphuret, and carburet of lead, possess nothing to excite special interest.

SECTION VII.

METALS, THE OXIDES OF WHICH ARE REDUCED TO THE METALLIC STATE BY A RED HEAT.

MERCURY, OR QUICKSILVER.

Symbol Hg; Equivalent 202.

754. This metal was well known to the ancients. The principal mines from which it is obtained, are those of Idria in Carniola, and Almaden in Spain; but it is also found in Italy, South America, in the East Indies, in Siberia, and in very small

quantities in England and France. It occurs in five different states, constituting five different species of mercurial ores. Native mercury is not uncommon; but by far the most abundant ore is *cinnabar*, which is a sulphuret of mercury. From this ore metal is extracted by heating it with lime or iron filings, by which means the mercury is volatilized and the sulphur retained. As prepared on a large scale, it is usually mixed in small quantity with other metals, from which it may be purified by cautious distillation.

755. Mercury is distinguished from all other metals by being fluid at common temperatures. It has a tin-white color and strong metallic lustre. It becomes solid at —39° or —40°; and in congealing, evinces a strong tendency to crystallize in octohedrons. It contracts greatly at the moment of congelation; for while its density at 47° is 13.55, that of frozen mercury is 15.61. When solid it is malleable, and may be cut with a knife. At 662° or near that degree, it enters into ebullition, and condenses again on cool surfaces into metallic globules.

In consequence of this metal being usually seen in the fluid state, and from its resemblance to silver, it has been called *hydrargyrum* (υδωρ αργυρος), *argentum vivum*, and *quicksilver*. It is generally imported into the United States in strong iron bottles, and when first taken from these bottles, is said to be generally very pure.

This metal, if quite pure, is not tarnished in the cold by exposure to air and moisture; but if it contain other metals, the amalgam of those metals oxydizes readily, and collects a film upon its surface. Mercury is said to be oxydized by long agitation in a bottle half full of air, and the oxide so formed was called by Boerhaave, *ethiops per se;* but it is very probable that the oxydation of mercury observed under these circumstances was solely owing to the presence of other metals. When mercury is exposed to air or oxygen gas, while in the form of vapor, it slowly absorbs oxygen and is converted into the peroxide.

The only acids that act on mercury are the sulphuric and nitric acids. The former has no action whatever in the cold; but on the application of heat, the mercury is oxydized at the expense of the acid, pure sulphurous acid gas is disengaged, and a sulphate of mercury is generated. Nitric acid acts energetically upon mercury, both with and without the aid of heat, oxydizing and dissolving it with evolution of binoxide of nitrogen.

756. Mercury is made use of for many important purposes, in medicine, in the laboratory, and in the arts. In the construction of thermometers and barometers it is absolutely essential, and for the mercurial bath, to enable the chemist to collect and transfer gases that are absorbed by water; and in union with various other substances it constitutes the bases of many im-

portant medicines. Several of these preparations will be described in their proper places.

AMALGAMS.

757. This term is exclusively applied to the compounds of mercury with the other metals.

Quicksilver unites with potassium when agitated in a glass tube with that metal, forming a solid amalgam. When the amalgam is put into water, the potassium is gradually oxydized, hydrogen gas is disengaged, and the mercury resumes its liquid form. A similar compound may be obtained with sodium. These amalgams may also be procured by placing the negative wire in contact with a globule of mercury during the process of decomposing potassa and soda by galvanism.

A solid amalgam of tin is employed in making looking-glasses; and an amalgam made of one part of lead, one of tin, two of bismuth, and four parts of mercury, is used for silvering the inside of hollow glass globes. This amalgam is solid at common temperatures; but it is fused by a slight degree of heat.

The amalgam of zinc and tin, used for promoting the action of the electrical machine, is made by fusing one part of zinc with one of tin, and then agitating the liquid mass with two parts of hot mercury placed in a wooden box. Mercury evinces little disposition to unite with iron, and on this account it is usually preserved in iron bottles.

MERCURY AND OXYGEN.

Chemists are acquainted with but two oxides of mercury, the protoxide and the peroxide.

	Mercury.	*Oxygen.*	*Equiv.*	*Symbols.*
Protoxide	1 eq.+	1 eq.	210	HgO
Peroxide	1 eq.+	2 eq.	218	HgO_2

758. *Protoxide of Mercury.*—This oxide is readily prepared by mixing calomel, which is a chloride of mercury (760), briskly in a mortar with pure potassa in excess, so as to effect its decomposition as rapidly as possible, and then wash the precipitate formed in cold water, and dry spontaneously in a dark place. These precautions are rendered necessary by the tendency of the protoxide to resolve itself into the peroxide and metallic mercury, a change which is easily effected by heat, by the direct solar rays, and even by daylight. It is on this account very difficult to procure protoxide of mercury in a state of absolute purity.

This oxide is a black powder, and is insoluble in water, but unites with the acids as a weak alkaline base.

759. *Peroxide of Mercury.*—This oxide may be formed either by the combined agency of heat and air, as already mentioned,

or by dissolving mercury in nitric acid, and exposing the nitrate so formed to a temperature just sufficient for expelling the whole of the nitric acid. It is commonly known by the name of *red precipitate*. The peroxide prepared from the nitrate almost always contains a trace of nitric acid, which may be detected by heating it in a clean glass tube by means of a spirit-lamp: a yellow ring, formed of subnitrate of oxide of mercury, collects within the tube just above the part which is heated.

Peroxide of mercury, thus prepared, is commonly in the form of shining crystaline scales, of a nearly black color while hot, but red when cold; when very finely levigated, the peroxide has an orange color. It is soluble to a small extent in water, forming a solution which has an acrid metallic taste, and communicates a green color (294 N.) to the blue infusion of violets. When heated to redness, it is converted into metallic mercury and oxygen. Long exposure to light has a similar effect.

This compound is extensively used in medicine.

MERCURY AND CHLORINE.

There are two compounds of mercury and chlorine, corresponding in composition to the two oxides, both of which are well known. Their relative composition is shown by the following table:

	Mercury.	*Chlorine.*	*Equiv.*	*Symbols.*
Protochloride	1 eq. +	1 eq.	237.42	$HgCl$
Bichloride	1 eq. +	2 eq.	272.84	$HgCl_2$

760. *Protochloride of Mercury.*—Protochloride of mercury, or *calomel*, is always generated when chlorine comes in contact with mercury at common temperatures; and also by the contact of metallic mercury and the bichloride. It may be made by precipitation, by mixing nitrate of protoxide of mercury in solution with hydrochloric acid, or any soluble chloride, as common salt; or by subliming from a mixture of metallic mercury and the bichloride.

Protochloride of mercury is a rare mineral production, called *horn quicksilver*, which occurs crystalized in quadrangular prisms, terminated by pyramids. When obtained by sublimation it is in semi-transparent crystaline cakes; but as formed by precipitation, it is a white powder. At a heat short of redness, but higher than the subliming point of the bichloride, it rises in vapor without previous fusion; but during the sublimation a portion is always resolved into mercury and the bichloride. It is yellow while warm, but recovers its whiteness on cooling. Its specific gravity is about 7.2. It is distinguished from the bichloride by not being poisonous, by having no taste, and by being exceedingly insoluble in water. Acids have little effect upon it; but pure alkalies decompose it, separating the black protoxide of mercury. The use of this compound in medicine is well known.*

761. *Bichloride of Mercury.*—When mercury is heated in chlorine gas it takes fire, and burns with a pale red flame, forming the well-known medicinal preparation and virulent poison, *corrosive sublimate*, or bichloride of mercury. It is prepared for medical purposes by subliming a mixture of bisulphate of the peroxide of mercury with chloride of sodium. The two substances, perfectly dry, should be intimately mixed, to insure no waste, in the exact proportion of one equivalent of the bisulphate to two equivalents of the chloride of sodium.

The chemical changes that take place during the process will be seen by the following formulæ: $HgO_2, 2SO_3+2NaCl=Hg, 2Cl+2NaO, SO_3$. The chlorine of the chloride of sodium is transferred to the mercury and the sulphuric acid of sulphate of mercury to the soda. The bichloride of mercury thus formed is sublimed, while the sulphate of soda, being fixed, remains in the retort.

762. Bichloride of mercury, when obtained by sublimation, is a semi-transparent colorless substance, of a crystaline texture. It has an acrid, burning taste, and leaves a nauseous metallic flavor on the tongue. Its specific gravity is 5.2. When exposed to a heat of 509°, it is fused, enters into ebullition from the rapid formation of vapor at 563°, and is deposited without further change on cool surfaces as a white crystaline sublimate. It requires twenty times its weight of cold, and only twice its weight of boiling water for solution, and is deposited from the latter, as it cools, in the form of prismatic crystals. Strong alcohol and ether dissolve it in the same proportion as boiling water; and it is soluble in half its weight of concentrated hydrochloric acid at the temperature of 70°. With the chlorides of potassium and sodium, hydrochlorate of ammonia, and several other bases, it enters into combination, forming double salts, which are more soluble than the chloride itself. When its solution in water is agitated with ether, the latter abstracts the bichloride, and rises with it to the surface of the former, thus affording strong evidence of the bichloride having existed as such in the water. Its aqueous solution is gradually decomposed by light, calomel being deposited.

From its watery solution the alkalies precipitate the peroxide; that produced by lime-water, being of a yellow color, is called in medicine *yellow wash.*

763. This substance, as its name indicates, is highly corrosive

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* The variety of names by which this substance has been known is a little amusing. The following are some of them:—*mercurius dulcis, draco mitigatus, sublimatum dulce, aquila alba, aquila mitigata, manna metallorum, panchymogogum minerale, panchymogogus quercetanus!*

in its action upon the animal system, even when applied externally. Taken internally, in sufficient quantities, it acts violently upon the throat, stomach, and intestines, producing inflammation and all its consequences, as vomiting, dysentery, &c. After death more or less corrosion is generally found to have taken place in those parts with which the poison has come in contact. Its action is scarcely less certain and destructive than that of arsenious acid, and it has therefore often been used as a means of death by the evil-designing! It therefore becomes an object of some importance to be able to detect its presence, when it is mixed with other substances.

764. The presence of mercury in a fluid supposed to contain corrosive sublimate, may be detected by concentrating and digesting it with an excess of pure potassa. Oxide of mercury, which subsides, is then sublimed in a small glass tube by means of a spirit-lamp, and obtained in the form of metallic globules. But in cases of poisoning, when the bichloride is mixed with organic substances, Christison recommends that the liquid, without previous filtration, be agitated with a fourth of its volume of ether, which separates the poison from the aqueous part, and rises to the surface. The ethereal solution is then evaporated on a watch-glass, the residue dissolved in hot water, and the mercury precipitated in the metallic state by protochloride of tin at a boiling temperature. If, as is probable, most of the poison is already converted into calomel, and thereby rendered insoluble, as many vegetable fibres should be picked out as possible, and the whole at once digested with protochloride of tin. The organic substances are then dissolved in a hot solution of caustic potassa, and the insoluble parts washed and sublimed to separate the mercury.

A very elegant method of detecting the presence of mercury is to place a drop of the suspected liquid on polished gold, and to touch the moistened surface with a piece of iron wire or the point of a penknife, when the part touched instantly becomes white, owing to the formation of an amalgam of gold.

As further tests for this substance, it may be remarked that sulphuretted hydrogen gives with it in a state of solution a black precipitate, solution of nitrate of silver a white, and iodide of potassium a pale scarlet precipitate.

765. Many animal and vegetable solutions convert bichloride of mercury into calomel, a portion of hydrochloric acid being set free at the same time. Some substances effect this change slowly; while others, and especially albumen, produce it in an instant. Thus, when a solution of corrosive sublimate is mixed with albumen, a white flocculent precipitate subsides, which Orfila has shown to be a compound of calomel and albumen, and which he has proved experimentally to be inert. Consequently a solution of the white of an egg is an antidote to poisoning by corrosive sublimate. The muscular and mem-

branous parts, even of a living animal, produce a similar effect; and the causticity of corrosive sublimate seems owing to the destruction of the animal fibre by which the decomposition of the bichloride is accompanied, and which constitutes an essential part of the chemical change.

766. Calomel and corrosive sublimate may always be distinguished from each other, by dropping on a small quantity of the dry powder a little solution of ammonia or other alkali, by which calomel is instantly turned black, but corrosive sublimate is unaffected. In solution they may be distinguished by the same means.

MERCURY AND SULPHUR.

Mercury and sulphur combine in two properties, forming the proto and bisulphurets.

	Mercury.	*Sulphur.*	*Equiv.*	*Symbols.*
Protosulphuret	1 eq. +	1 eq.	218.1	HgS
Bisulphuret	1 eq. +	2 eq.	234.2	HgS_2

767. *Protosulphuret of Mercury* possesses little interest. It is of a black color, and may be formed by transmitting a current of hydrosulphuric acid through a dilute solution of the protonitrate of mercury. It has been called *ethiops mineral.*

768. *Bisulphuret of Mercury.*—This compound, as before remarked, occurs native, and constitutes the most abundant ore of mercury, and is known by the name of *cinnabar*. It may also be formed artificially by fusing sulphur with about six times its weight of mercury, and subliming in close vessels. When procured by this process it has a red color, and is known by the name of *factitious cinnabar*. Its tint is greatly improved by being reduced to powder, in which state it forms the beautiful pigment *vermilion*. It may be obtained in the moist way by pouring a solution of corrosive sublimate into an excess of hydrosulphate of ammonia. A black precipitate subsides, which acquires the usual red color of cinnabar when sublimed. Other methods of forming it need not here be detailed.

Cinnabar is not attacked by alkalies, or any simple acid; but it is dissolved by the nitro-hydrochloric, with formation of sulphuric acid and peroxide of mercury.

769. *Iodides of Mercury.*—Iodine forms with mercury a protiodide, sesquiodide, and biniodide of mercury, the last of which only will be described.

770. *Biniodide of Mercury* may be formed by mixing a solution of pernitrate or bichloride of mercury, with solution of iodide of potassium. If either of the substances is in excess, the beautiful red biniodide that is formed is immediately redissolved, and of course disappears.

The biniodide, when exposed to a moderate heat, gradually becomes yellow; and the particles, though previously in powder, acquire a crystaline appearance. At about 400° it forms a yellow liquid which slowly sublimes in small transparent scales, or in large rhombic tables, when a considerable quantity is sublimed. The crystals retain their yellow color at 60°, if kept very tranquil; but if the temperature be below a certain point, or they are rubbed or touched, they quickly become red. This phenomenon is entirely due to a change in molecular arrangement; the different colors so often witnessed in the same substances at different temperatures, as in peroxide of mercury and the protoxides of lead and zinc, appear to be phenomena of the same nature.

This compound has been used by painters as a substitute for vermilion, but its color, it is said, is less permanent.

The bromides, phosphurets, fluorides, &c., of mercury, are not here described.

SILVER.

Symbol Ag; Equivalent 108.

771. THIS metal was known to the ancients. It frequently occurs native in silver mines, both massive and in octohedral or cubic crystals. It is also found in combination with gold, tellurium, antimony, copper, arsenic, and sulphur. In the state of sulphuret it so frequently accompanies galena, that the lead of commerce is rarely quite free from traces of silver.

Nearly all the silver obtained from the mines at the present time is found native or is extracted from the sulphuret, but, according to Thompson, there are no less than seventeen species of silver ores.

Silver is extracted from its ores by two processes, which are essentially distinct: one of them being contrived to separate it from lead; the other, the process by *amalgamation*, being especially adapted to those ores which are free from lead.

In the process first mentioned, the ore of silver being triturated with mercury, the two metals combine, forming an amalgam, which is easily separated from other impurities. The mercury is afterwards expelled by heat.

The principle of its separation from lead is founded on the different oxydability of lead and silver, and on the ready fusibility of litharge. The lead obtained from those kinds of galena which are rich in sulphuret of silver is kept at a red heat in a flat furnace, with a draught of air constantly playing on its surface: the lead is thus rapidly oxydized; and as the oxide, at the moment of its formation, is fused, and runs off through an aperture in the side of the furnace, the production of litharge goes on uninterruptedly, until all the lead is removed. The button of silver is again fused in a smaller furnace, resting on a porous earthen dish, made with lixiviated wood-ashes, called a *test* or *cupel*, the porosity of which is so great, that it absorbs any remaining portions of litharge which may be formed on the silver.

772. Silver has the clearest white color of all the metals, and is susceptible of receiving a lustre surpassed only by polished

steel. In malleability and ductility it is inferior only to gold, and its tenacity is considerable.

It may be drawn out into a wire so fine that 400 feet will be required to weigh a single grain.

It is very soft when pure, so that it may be cut with a knife. Its density, after being hammered, is 10.51. At a full red heat, corresponding to 1873°, it enters into fusion.

Pure silver does not rust by exposure to air and moisture. When fused in open vessels it absorbs oxygen in considerable quantity, amounting sometimes to 22 times its volume; but it parts with the whole of it in the act of becoming solid.

This absorption, and consequent evolution of oxygen, is much the most abundant in the purest silver, and is entirely prevented by the presence of a very small per centage of copper. When pure silver is melted, a portion is often lost during the cooling by the spirting produced by the escape of the oxygen.

The only pure acids that act on silver are the sulphuric and nitric acids, by both of which it is oxydized, forming with the first a sulphate, and with the second a nitrate of oxide of silver. It is not attacked by sulphuric acid, unless aided by heat. Nitric acid is its only proper solvent.

773. Silver is used in every country for many important purposes—for coin and for manufacture into various articles of utility or ornament.

Silver coin is always alloyed with copper to increase its hardness, and render it less liable to be worn by use. In Great Britain, it is said, standard silver is composed of silver 11 parts, and copper 1 part; in the United States and France, of silver 9½ parts, and copper 1 part nearly.

Utensils and ornaments of silver are usually made of standard silver, and are fashioned by hammering, as silver does not cast well. Articles of irregular or complex form are made in several pieces, which are afterwards soldered together, and the beautiful appearance of fine silver is given to the whole surface by boiling the articles a few minutes in a very dilute sulphuric acid, which dissolves out the copper and leaves the silver of a dead white, and ready for the burnisher.

When silver is exposed to the air it gradually tarnishes, which is due not to the formation of an oxide but a sulphuret, the air always containing traces of hydrosulphuric acid derived from organic bodies. This gas is also produced during the combustion of mineral coal; and portions of it are always escaping from the stoves or furnaces in which it is consumed into the apartments where *articles of silver* are kept.

ALLOYS OF SILVER.

774. Silver is capable of uniting with most other metals, and suffers greatly in malleability and ductility by their presence

It may contain a large quantity of copper without losing its white color.

An amalgam of silver occurs as a mineral production.

An alloy of silver and brass is used as a solder for silver.

SILVER AND OXYGEN.

There is not a perfect agreement among chemists with regard to the compounds of silver and oxygen, but there seems to be but one well determined—the protoxide.

	Silver.	*Oxygen.*	*Equiv.*	*Symbol.*
Protoxide	1 eq. +	1 eq.	116	AgO

775. *Protoxide of Silver.*—This compound is best procured by mixing a solution of pure baryta with nitrate of oxide of silver dissolved in water. It is of a brown color, insoluble in water, and is completely reduced by a red heat.

Silver is separated from its solution in nitric acid by pure alkalies and alkaline earths, as the brown oxide, which is redissolved by ammonia in excess; by alkaline carbonates as a white carbonate, which is soluble in an excess of carbonate of ammonia; as a dark brown sulphuret by hydrosulphuric acid; and as a white curdy chloride of silver, which is turned violet by light and is very soluble in ammonia, by hydrochloric acid or any soluble chloride. By the last character, silver may be both distinguished and separated from other metallic bodies.

Silver is precipitated in the metallic state by most other metals. When mercury is employed for this purpose, the silver assumes a beautiful arborescent appearance, called *arbor Dianæ.* A very good proportion for the experiment is twenty grains of lunar caustic to six drachms or an ounce of water. The silver thus deposited always contains mercury.

When oxide of silver, recently precipitated by baryta or lime water, and separated from adhering moisture by bibulous paper, is left in contact for ten or twelve hours with a strong solution of ammonia, the greater part of it is dissolved; but a black powder remains which detonates violently from heat or percussion. This substance appears to be a compound of ammonia and oxide of silver; for the products of its detonation are metallic silver, water, and nitrogen gas. It should be made in very small quantity at a time, and dried spontaneously in the air.

SILVER AND CHLORINE.

There is but a single compound of silver and chlorine, which is composed as follows:

	Silver.	*Chlorine.*	*Equiv.*	*Symbol.*
Chloride	1 eq. +	1 eq.	143.42	AgCl.

776. *Chloride of Silver.*—This compound is sometimes found native, and is called *horn silver.* It is always generated when silver is heated in chlo-

rine gas, and may be prepared conveniently by mixing hydrochloric acid or any soluble chloride, with a solution of nitrate of oxide of silver. As formed by precipitation it is quite white; but by exposure to the direct solar rays it becomes violet, and almost black in the course of a few minutes; and a similar effect is slowly produced by diffused daylight.

It is insoluble in water, and only sparingly soluble in the strongest acids, but dissolves readily in ammonia and hyposulphurous acid.

At a temperature of about 500° it fuses, and forms a semi-transparent, horny mass on cooling, which has a density of 5.52. It bears any degree of heat, or even the combined action of pure charcoal and heat, without decomposition; but hydrogen gas decomposes it readily with formation of hydrochloric acid.

For the full change of color to take place, the presence of organic matter appears to be necessary. The relations of this substance to light are of the highest importance in photography (155), in which branch of science it serves a very important purpose.

Sulphuret of Silver often occurs native (771), and is called *silver glance* by mineralogists. There is considerable affinity between the two substances, and they may be made to combine by heating thin plates of silver with alternate layers of sulphur. The tarnish that forms upon articles of silver by use, is generally a sulphuret (773) of the metal.

Silver forms compounds also with iodine, bromine, and phosphorus.

GOLD.

Symbol Au; Equivalent 199.2.

777. Gold appears to have been known to the earliest races of men, and to have been esteemed by them as much as by the moderns. It has hitherto been found only in the metallic state, either pure or in combination with other metals. It occurs massive, capillary, in grains, and crystalizes in octohedrons and cubes, or their allied forms. It is sometimes found in primary mountains, but more frequently in alluvial depositions, especially among sand in the beds of rivers, having been washed by water out of disintegrated rocks in which it originally existed.

It occurs in almost every country, but most of it is obtained from the mines of South America, Hungary, and the Uralian mountains. It is also found in several of the United States, particularly in North Carolina, Virginia, and Georgia.

As gold exists in its ores in the metallic state, it is generally separated from them by the process of amalgamation, similar to that already described for obtaining silver (771), by which means it is separated from all other metals except silver. To remove this so much silver must be added that the gold shall constitute but a fourth of the whole, and the mass immersed in nitric acid, which then readily acts upon it, dissolving out all the silver, and leaving the gold in a state of purity.

This process has been called *quartation*. It may also be separated from other metals, except silver, by cupellation (771).

Gold is the only metal which has a yellow color, a character by which it is distinguished from all other simple metallic bodies. It is capable of receiving a high lustre by polishing, but is inferior in brilliancy to steel, silver, and mercury. In ductility and malleability it exceeds all other metals; but it is surpassed by several in tenacity.

It may be beaten out into leaves so thin, that one grain of gold will cover 56¾ square inches of surface. These leaves are only $\frac{1}{282000}$ of an inch in thickness, but the gold leaf with which silver wire is covered is only $\frac{1}{12}$ as thick. One ounce of gold upon silver wire is capable of being extended more than 1300 miles in length!

The density of gold is 19.26, but by being hammered it is increased. When pure, it is very soft and flexible, and fuses at about 2016°.

778. Gold and silver have long been known as the "precious metals;" and their purity has been estimated in carats. A carat is $\frac{1}{24}$th part of the mass; and to say the metal is twenty-three carats fine, is to say that it contains $\frac{23}{24}$ parts of pure metal, the rest being alloy. In England, standard gold is 22 carats fine, that is, it is composed of 11 parts of pure gold and one part alloy, which may be either copper or a mixture of equal parts of copper and silver.*

Standard gold in this country differs but little from that of England.

Besides its use for coin, gold is employed in the manufacture of a great many articles, which are chiefly ornamental. In the United States both gold and silver coin are melted down for use in the arts; but in England, and some other countries, this is forbidden by law.

Gold may be exposed for ages to air and moisture without change, nor is it oxydized by being kept in a state of fusion in open vessels. When intensely ignited by means of electricity, or the oxy-hydrogen blowpipe, it burns with a greenish-blue flame, and is dissipated in the form of a purple powder, which is supposed to be an oxide.

Gold is not oxydized or dissolved by any of the pure acids; for it may be boiled even in nitric acid without undergoing any change. Its best solvents are chlorine and nitro-hydrochloric acid; and it appears from the observations of Davy that chlorine is the agent in both cases, since nitro-hydrochloric acid does not dissolve gold, except when it gives rise to the formation of chlorine. It is inferred, therefore, that the chlorine unites directly with the gold. It is also readily attacked by fluorine.

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* It is said that a few years ago a considerable business was carried on in Paris, by importing British sovereigns and extracting the silver by a peculiar and cheap process, and supplying its place with an equal weight of copper. It was then, in ingots, sent back to England, where, being still 22 carats fine, it was worth just as much as before! Much of it was again recoined into sovereigns, which may be known by their deeper color.—(*Jacobs' "Historical Inquiry" concerning the precious metals.*)

The most convenient method of dissolving it, is to digest fragments of the metal in a mixture composed of two measures of hydrochloric and one of nitric acid, until the acid is saturated. The excess of acid is then expelled by evaporating the orange-colored solution until a ruby-red liquid remains, which is the neutral terchloride of gold. On adding water, the chloride is dissolved, forming a solution of a gold-yellow color.

ALLOYS OF GOLD.

779. Some of the alloys of gold have already been alluded to as being used in coinage, and in the arts.

The presence of other metals in gold has a remarkable effect in impairing its malleability and ductility. The metals which possess this property in the greatest degree are bismuth, lead, antimony, and arsenic. Thus, when gold is alloyed with $\frac{1}{1920}$ part of its weight of lead, its malleability is surprisingly diminished. A very small portion of copper has an influence over the color of gold, communicating to it a red tint, which becomes deeper as the quantity of copper increases. Pure gold, being too soft for coinage and many purposes in the arts, is always alloyed either with copper or an alloy of copper and silver, which increases the hardness of the gold without materially affecting its color or tenacity.

Nearly all the gold found in nature is alloyed more or less with silver. In a late elaborate investigation into the constituents of the Uralian ores of gold, G. Rose found one specimen with 0.16 per cent. of silver, and another with 38.38 per cent.; but most of the specimens contained 8 or 9 per cent. of silver. It has been maintained that the native alloys of gold and silver are usually in atomic proportion, but this has been disproved; and being isomorphous (361) it is to be expected that like other isomorphous bodies, these metals will be found crystalized with each other in proportions altogether indefinite.

Gold unites with remarkable facility with mercury, forming a white colored compound. An amalgam composed of one part of gold and eight of mercury is employed in gilding brass. The brass, after being rubbed with nitrate of oxide of mercury, in order to give it a thin film of quicksilver, is covered with the amalgam of gold, and then exposed to heat for the purpose of expelling the mercury.

GOLD AND OXYGEN.

Gold forms with oxygen three compounds, as exhibited in the following table:

	Gold.	*Oxygen.*	*Equiv.*	*Symbols*
Protoxide	1 eq. +	1 eq.	207.2	AuO
Binoxide	1 eq. +	2 eq.	215.2	AuO_2
Teroxide	1 eq. +	3 eq.	223.2	AuO_3

The *protoxide* and *binoxide* of gold possess little interest; indeed the existence of the latter is doubted by many.

780. *Teroxide of Gold.*—This, the only well-known oxide of gold, is prepared by the action of alkalies on the terchloride, but is obtained quite pure with difficulty. Pelletier recommends that it should be formed by digesting a solution of the terchloride with pure magnesia, washing the precipitate with water, and removing the excess of magnesia by dilute nitric acid. It is apt, however, to retain magnesia; and other more complicated processes are resorted to when it is desired to obtain it in great purity.

Teroxide of gold is yellow in the state of hydrate, and nearly black when anhydrous, is insoluble in water, and completely decomposed by solar light or a red heat. Hydrochloric acid dissolves it readily, yielding the common solution of gold; but it forms no definite compound with any acid which contains oxygen. It may indeed be dissolved by nitric and sulphuric acids; but the affinity is so slight, that the oxide is precipitated by the addition of water. It combines, on the contrary, with alkaline bases, such as potassa and baryta, apparently forming regular salts, in which it acts the part of a weak acid. It has been proposed, therefore, to call it *auric acid.*

781. When recently precipitated peroxide of gold is kept in strong ammonia for about a day, a detonating compound of a deep olive color ~~is generated~~ analogous to the fulminating silver described above (775). According to the analysis of Dumas, its elements are in the ratio of one equivalent of gold, two of nitrogen, six of hydrogen, and three of oxygen, as expressed by the symbols Au, N_2, H_6, O_3. Its detonation should give rise to metallic gold, water, nitrogen, and ammonia. A similar compound is obtained, and this is the ordinary mode of procuring fulminating gold, by digesting terchloride of gold with an excess of ammonia; a yellow precipitate subsides, the fulminating ingredient of which appears identical with that above described.

This oxide is used in coloring porcelain purple, and in the preparation of artificial mineral teeth to imitate the color of the gums.

GOLD AND CHLORINE.

But two compounds of gold and chlorine are known, the protochloride and the terchloride, and even these seem not to be perfectly understood.

	Gold.	*Chlorine.*	*Equiv.*	*Symbols.*
Protochloride	1 eq. +	1 eq.	234.6	$AuCl$
Terchloride	1 eq. +	3 eq.	305.4	$AuCl_3$

782. *Chlorides of Gold.*—On concentrating the solution of gold to a sufficient extent by evaporation, the *terchloride* may be obtained in ruby-red prismatic crystals, which are very fusible. It deliquesces on exposure to the air, and is dissolved readily by water without residue. It is also soluble in alcohol and ether; and the latter withdraws it from the aqueous solution. It begins to lose chlorine at about 400°, and at 600° the erchloride is completely resolved into the yellow insoluble protochloride. At a red heat the chlorine is entirely expelled, and metallic gold remains.

Solution of the terchloride of gold is very easily decomposed by various substances, as sulphate of the protoxide of iron, sulphurous and phosphorous acids, and most of the metals.

When a piece of charcoal is immersed in a solution of gold and exposed to the direct solar rays, its surface acquires a coating of metallic gold, and ribands may be gilded by moistening them with a dilute solution of gold, and exposing them to a current of hydrogen or phosphuretted hydrogen gas.

Sulphuric ether does not act directly upon gold, but when a strong aqueous solution of the terchloride of gold is shaken in a vial with an equal volume of pure ether, two fluids result, the lighter of which is an ethereal solution of gold. From this liquid flakes of metal are deposited on standing, especially by exposure to light, and substances moistened with it receive a coating of metallic gold.

This method of gilding is adopted to some extent in the arts, but to insure success several precautions must be observed. The solution should be very strong and contain no free acid. After the acid is saturated with gold, the solution should be evaporated to perfect dryness, and again dissolved in distilled water.

783. When protochloride of tin is added to a dilute aqueous solution of gold, a purple-colored precipitate, called the *purple of Cassius*, is thrown down; and the same substance may be prepared by fusing together 150 parts of silver, 20 of gold, and 35.1 of tin, and acting on the alloy with nitric acid, which dissolves out the silver and leaves a purple residue, containing the tin and gold which were employed. To prevent the oxydation of the tin during fusion, the three metals should be projected into a red-hot black-lead crucible, which contains a little melted borax. When the powder of Cassius is fused with vitreous substances, such as flint-glass, or a mixture of sand and borax, it forms with them a purple enamel, which is employed in giving pink colors to porcelain.

The chemical nature of the purple of Cassius is very obscure, but it is probably a compound of the oxide of tin and the purple oxide of gold, in which one of the oxides acts the part of an acid, and the other as a base.

Gold may also be made to combine with bromine, iodine, sulphur, and phosphorus.

PLATINUM.

Symbol Pt; Equivalent 98.8.

784. **Platinum**, unlike gold, was entirely unknown in the world, as a distinct metal, until the year 1741, when some of it was sent to Europe from Jamaica, by Mr. Wood; but no description of it appeared till 1749.

This valuable metal occurs only in the metallic state, associated or combined with various other metals, such as copper, iron, lead, titanium, chromium, gold, silver, palladium, rhodium, osmium, and iridium. It has hitherto been found chiefly in Brazil, Peru, and other parts of South America, in the form of rounded or flattened grains of a metallic lustre and white color, mixed with sand and other alluvial depositions. In 1826, it was discovered in a sienitic rock, in South America, associated with gold. Rich mines of gold and platinum have been discovered in the Uralian mountains.

The process for reducing crude platinum to ingots of the pure malleable metal, was brought to perfection by Wollaston, an account of which was published in the Philosophical Transactions for 1829. It consists in dissolving the crude metal in nitro-hydrochloric acid, precipitating with a solution of hydrochlorate of ammonia, and subjecting the fine powder thus obtained to violent pressure in a brass tube. By this means the metal, in a state of minute division, is firmly compressed together; and by heating to the highest temperature of a smith's forge, and carefully hammering, it is perfectly closed, all the parts being effectually welded together. Several precautions are to be observed in different parts of the process, which it is not necessary here to detail.

785. Pure platinum has a white color, very much like silver, but of inferior lustre. It is the heaviest of known metals, its density after forging being about 21.25, and 21.5 in the state of wire. Its malleability is considerable, though far less than that of gold and silver. It may be drawn into wires, the diameter of which does not exceed the 2000th part of an inch. It is a soft metal, and like iron admits of being welded (664) at a high temperature. It is a less perfect conductor of heat than several other metals.

Platinum undergoes no change from the combined agency of air and moisture; and it may be exposed to the strongest heat of a smith's forge, without suffering either oxydation or fusion. On heating a small wire of it by means of galvanism or the oxy-hydrogen blowpipe (384), it is fused, and afterwards burns with the emission of sparks.

It may be oxydized by heating it with nitrate of potassa, or with pure potassa or lithia. None of the pure acids attack it, but it is dissolved in the nitro-hydrochloric acid, but not so readily as gold.

786. When platinum is precipitated from its solution in nitro-hydrochloric acid by hydrochlorate of ammonia, and heated to redness, it is left in a minutely divided state, which has been called *spongy platinum.* This substance possesses the remarkable property of inflaming a mixture of oxygen and hydrogen, even when perfectly cold (382). The effect is the same if a jet of hydrogen in the air is made to fall upon the spongy metal. It has been more recently discovered that asbestos and charcoal, which have been soaked in the platinum solution, and afterwards dried and ignited, possess the same property. Platinum, in the compact form of wire or foil, is also found capable of causing the union of these gases, provided the surface is *perfectly clean.*

Platinum is employed in the manufacture of many indispensable articles for the laboratory of the chemist, and in the arts. Retorts for concentrating sulphuric acid are made of it, notwithstanding its great expense, which is generally six or seven times that of silver. The Russian government some years ago issued a coinage of it, but were subsequently obliged to recall it, in consequence of the rapid diminution of its value that took place, occasioned by the abundant supply of the metal in the market. Dr. Hare has recently introduced some improvements in the working of this metal, by inventing a method of melting large masses of it, by means of his compound blowpipe, as before stated.

Platinum is capable of combining with other metals, forming alloys, but little is known of them. Allusion has already been made (677) to the alloys of platinum with steel.

PLATINUM AND OXYGEN.

These substances combine in two proportions, forming a protoxide and a peroxide.

	Platinum.	*Oxygen.*	*Equiv.*	*Symbols.*
Protoxide	1 eq. +	1 eq.	106.8	PtO
Binoxide	1 eq. +	2 eq.	114.8	PtO_2

787. *Protoxide of Platinum.*—This oxide is prepared by digesting protochloride of platinum in a solution of pure potassa, avoiding a large excess of the alkali, since it dissolves a portion of the oxide, and thereby acquires a green color. In this state it is a hydrate, which loses first its water and then oxygen when heated, and dissolves slowly in acids, yielding solutions of a brownish-green tint.

788. *Binoxide of Platinum.*—This oxide is prepared with difficulty, owing to its disposition, like peroxide of gold (780), to act rather as an acid than as an alkaline base, and either to fall in combination with any alkali by which it is precipitated, or

to remain with it altogether in solution. Berzelius recommends that it should be prepared by exactly decomposing sulphate of binoxide of platinum with nitrate of baryta, and adding pure soda to the filtered solution, so as to precipitate about half of the oxide, since otherwise a sub-salt would subside. The oxide falls in the form of a bulky hydrate, of a yellowish-brown color: it resembles rust of iron when dry, and is nearly black when rendered anhydrous.

PLATINUM AND CHLORINE.

There are but two well-determined compounds of platinum and chlorine.

	Platinum.	*Chlorine.*	*Equiv.*	*Symbols.*
Protochloride	1 eq. +	1 eq.	134.22	$PtCl$
Bichloride	1 eq. +	2 eq.	169.64	$PtCl_2$

789. *Protochloride of Platinum* is formed by heating the bichloride to about 450°, by which half its chlorine is expelled. It is insoluble in water; by heat it is decomposed.

790. *Bichloride of Platinum.*—This chloride is obtained by evaporating the solution of platinum in nitro-hydrochloric acid to dryness, at a very gentle heat, when it remains as a red hydrate, which becomes brown when its water is expelled. It is deliquescent, and very soluble in water, alcohol, and ether; its solution, if free from the chlorides of palladium and iridium, being of a pure yellow color. Its ethereal solution is decomposed by light metallic platinum being deposited.

A solution of platinum is recognized by the following characters. When to an alcoholic or concentrated aqueous solution of the bichloride, a solution of chloride of potassium is added, a crystaline double chloride of a pale yellow color subsides, which is insoluble in alcohol, and sparingly soluble in water: at a red heat it yields chlorine gas, and the residue consists of metallic platinum and chloride of potassium. With a solution of hydrochlorate of ammonia a similar yellow salt falls, which when ignited leaves pure platinum in the form of a delicate spongy mass, the power of which in kindling an explosive mixture of oxygen and hydrogen gases has already been mentioned.

Platinum combines also with iodine and sulphur, forming compounds analogous to the oxides and chlorides. With phosphorus it unites in three proportions.

PALLADIUM, RHODIUM, OSMIUM, AND IRIDIUM.

791. These four metals are all contained in the ore of platinum, and have hitherto been procured in very small quantity. When the ore is digested in nitro-hydrochloric acid, the platinum, together with palladium, rhodium, iron, copper, and lead, is dissolved; while a black powder is left, consisting of osmium and iridium.

The two former, palladium and rhodium, were discovered by Wollaston, in 1803, and described by him a year or two afterwards. They are capable of uniting with several of the metals and some non-metallic substances, but the student is referred to more extended works for the descriptions of the compounds, as well as of the metals themselves.

792. *Rhodium*, it is said, has lately been used for tipping pens made of gold, on account of its great hardness and little liability to be corroded by the action of the ink.

793. *Osmium* and *iridium* were discovered by Tennant in the same year, 1803. They also combine with several of the metals and other substances. No use, it is believed, has been made of either of them in the arts.

Each of these four metals possesses some useful properties, and should they ever be found in sufficient quantity, they will unquestionably be made available for important purposes.

The symbols and equivalents of these metals will be found in the table, page 136.

CHAPTER IV.

SALTS.

SECTION I.

GENERAL REMARKS.

794. The preceding pages contain the description either of elementary principles, or of compounds immediately resulting from the union of those elements. These compounds are bi-elementary, that is, arise from the union of two elements (338); and their constituents are regarded, according to the electro-chemical theory (282) as possessing opposite electric energies, and as combined by virtue of such energies; and the names applied to them are partly constructed (303) in reference to this theory. Thus in compounds of oxygen and chlorine, chlorine and iodine, sulphur and potassium, the term expressive of the genus or class of bodies to which each compound belongs, is derived from the electro-negative element; so that we do not say chloride of oxygen, iodide of chlorine, and potassiuret of sulphur, but oxide of chlorine, chloride of iodine, and sulphuret of potassium; because oxygen has a higher electro-negative energy than chlorine, chlorine than iodine, and sulphur than potassium. The metals, as a class, are electro-positive to the non-metallic elements; but in relation to each other some of the metals are electro-positive, and others electro-negative. To the former belong those metals, the oxides of which are strong alkaline bases, such as potassium, sodium, and calcium; and among the latter are enumerated those, such as arsenic, antimony, and molybdenum, which are prone to form acids when they unite with oxygen.

795. Some of the bi-elementary compounds above referred to, though composed of very energetic elements, are themselves chemically indifferent, manifesting little disposition to unite with any other body whatever; of which the peroxides of

manganese and lead, and some of the chlorides, are examples. Others, on the contrary, are surprisingly energetic in their chemical relations, and have an extensive range of affinity. The most remarkable instances of this are found among those oxydized bodies called *acids* and *alkalies*, the characters of which fixed the attention of chemists long before their composition was understood. The acids and alkalies, however, are indifferent to elementary substances: their affinities are exerted towards each other, and by uniting they give rise to compounds more complex than themselves, as containing at least three elements, and which are known by the name of *salts*. Acids and alkalies possess opposite electric energies in relation to each other, the former being negative, and the latter positive. The electric energies evinced by them are related to the electric energies of their elements. Thus acids generally abound in the electro-negative oxygen, and if they contain a metal, it is usually an electro-negative metal; whereas the powerful alkalies are the protoxides of electro-positive metals.

796. Acids and alkalies neutralize each other more or less completely, so that the resulting salt is generally neither acid nor alkaline, and is far less energetic as a chemical agent than acids and alkalies. Most of them, however, unite in definite proportion with certain substances, such as water, alcohol, ammonia, and with other salts, forming the extensive family of *double salts*. To these compounds the electro-chemical theory may be extended: the two simple salts which constitute a double salt may be viewed as two molecules united by virtue of electric energies of an opposite character.

In the early period of modern chemistry, an acid was considered to be an oxydized body which has a sour taste, reddens litmus paper, and neutralizes alkalies. But subsequent experience has shown the propriety of extending the definition of the term; and chemists are accustomed to consider as acids all those compounds which unite with potassa or ammonia, and give rise to bodies similar in their constitution and general character to the salts which the sulphuric or some admitted acid forms with those alkalies.

797. So also it is agreed to place among the *alkaline* or *salifiable bases*, all those bodies which unite definitely with admitted acids, such as the sulphuric and nitric, and form with them compounds analogous in constitution to the salts which admitted alkalies form with the acids.

The progress of chemistry, which has produced this change of view, as regards the true nature of the acids and alkalies, has also caused an extension in the idea of a salt. The great mass of the salts are compounds of oxydized bodies, both the acid and the base containing oxygen. But ammonia, though not an acid, has all the characters of alkalinity in an eminent degree, and its compounds with the acids have always been admitted into the list of salts, as well as the compounds of the hydracids (which of course contain no oxygen) with the alkaline bases. Hence arose the division of the salts as a class into two orders, the one containing the oxygen or oxy-salts, and the other the hydrogen or hydro-salts.

798. These orders are still retained, though the notion of a salt has been still further extended. Chemists have long known that metallic sulphurets occasionally combine together, and constitute what is called a *double sulphuret.* In these compounds, Berzelius, whose labors have greatly added to their number, has traced an exact analogy with the salts, and applied to them the name of *sulphur-salts.* The simple sulphurets, by the union of which a sulphur-salt is formed, are bi-elementary compounds, strictly analogous in their constitution to acids and alkaline bases, and which like them are capable of assuming opposite electric energies in relation to each other. Electro-positive sulphurets, termed *sulphur-bases*, are usually the proto-sulphurets of electro-positive metals, and, therefore, correspond to the alkaline bases of those metals; and the electro-negative sulphurets, *sulphur-acids*, are the sulphurets of electro-negative metals, and are proportional in composition to the acids which the same metals form with oxygen. Hence, if the sulphur of a sulphur-salt were replaced by an equivalent quantity of oxygen, an oxy-salt would result.

The compounds which Berzelius has enumerated as sulphur-acids, are the sulphurets of arsenic, antimony, tungsten, molybdenum, tellurium, tin, and gold. To these he has added the sulphurets of several other substances not metallic, such as sulphuret of selenium, bisulphuret of carbon, and hydrosulphuric acid. These double sulphurets, thus formed, are therefore considered as a third order of salts.

799. A fourth order of salts is formed by the union of the chlorides, iodides, bromides, fluorides, &c. As the chlorides of the different elementary substances, like the sulphurets, may be divided into the two classes of chloro-acids and chloro-bases, we might make a separate order of chloro-salts; and the same might be said of the iodides, bromides, &c. But as the number of these is comparatively small, they are all brought together in the fourth order of *haloid salts*, (from αλς, *sea-salt*, and ειδος, *form*). They receive this name from the fact that their electro-negative and electro-positive elements are analogous in composition to common salt.

We have, therefore, the following four orders of salts, viz.:

Order I.—The oxy-salts. This order includes no salt the acid or base of which is not an oxydized body.

Order II.—The hydro-salts. This order includes no salt the acid or base of which does not contain hydrogen.

Order III.—The sulphur-salts. This order includes no salt the electro-positive or negative ingredient of which is not a sulphuret.

ORDER IV.—The haloid-salts. This order includes no salt the electro-positive or negative ingredient of which is not haloidal.

The salts are very numerous, but the whole number cannot yet be determined.

800. Nearly all salts are solid at common temperatures, and most of them are capable of crystalizing. The color of salts is very variable, having no necessary connection with the color of their elements. Salts composed of a colorless acid and base are colorless; but a salt, though formed of a colored oxide or acid, may be colorless; or, if colored, the tint may differ from that of both of its constituents.

All soluble salts are more or less sapid, while those that are insoluble in water are insipid. Few salts are possessed of odor: the most remarkable one for this property is carbonate of ammonia.

801. Salts differ remarkably in their affinity for water. Thus some salts, such as the nitrates of lime and magnesia, are *deliquescent*, that is, attract moisture from the air, and become liquid. Others, which have a less powerful attraction for water, undergo no change when the air is dry, but become moist in a humid atmosphere; and others may be exposed without change to an atmosphere loaded with watery vapor.

802. Salts differ likewise in the degree of solubility in water. Some dissolve in less than their weight of water; while others require several hundred times their weight of this liquid for solution, and others are quite insoluble. This difference depends on two circumstances, namely, on their affinity for water, and on their cohesion: their solubility being in direct ratio with the first, and in inverse ratio with the second. One salt may have a greater affinity for water than another, and yet be less soluble; an effect which may be produced by the cohesive power of the salt which has the stronger attraction for water, being greater than that of the salt which has a less powerful affinity for that liquid. The method proposed by Gay-Lussac for estimating the relative degrees of affinity of salts for water is by dissolving equal quantities of salts in equal quantities of water, and applying heat to the solutions. That salt which has the greatest affinity for the menstruum will retain it with most force, and will, therefore, require the highest temperature for boiling.

803. Salts which are soluble in water crystalize more or less regularly when their solutions are evaporated. If the evaporation is rendered rapid by heat, the salt is usually deposited in a confused crystaline mass; but if it take place slowly, regular crystals are formed. The best mode of conducting the process is to dissolve a salt in hot water, and when it has become quite cold, to pour the saturated solution into an evaporating

basin, which is to be set aside for several days or weeks without being moved. As the water evaporates, the salt assumes the solid form; and the slower the evaporation, the more regular are the crystals. Some salts which are much more soluble in hot than in cold water, crystalize with considerable regularity when a boiling saturated solution is slowly cooled. The form which salts assume in crystalizing is constant under the same circumstances, and constitutes an excellent character by which they may be distinguished from one another.

804. Many salts during the act of crystalizing unite chemically with a definite portion of water, which forms an essential part of the crystal, and is termed *water of crystalization* (350). The quantity of combined water is very variable in different saline bodies, but it is uniform in the same salt. A salt may contain more than half its weight of water, and yet be quite dry. On exposing a salt of this kind to heat, it is dissolved, if soluble, in its own water of crystalization, undergoing what is termed the *watery fusion*. By a strong heat, the whole of the water is expelled; for no salt can retain its water of crystalization when heated to redness. Some salts, such as sulphate and phosphate of soda, lose a portion of their water, and crumble down into a white powder, by mere exposure to the air, a change which is called *efflorescence*. The tendency of salts to undergo this change depends on the dryness and coldness of the air; for a salt which effloresces rapidly in a moderately dry and warm atmosphere, may often be kept without change in one which is damp and cold.

805. The water of crystalization is retained by a very feeble affinity, as is proved by the phenomena of efflorescence, and by the facility with which such water is separated from the saline matter by a moderate heat, or by exposure to the vacuum of an air-pump at common temperatures. But it is often observed that a portion of water is retained by a salt with such obstinacy that it cannot be expelled by a temperature short of that at which the salt is itself decomposed. This water is considered to act the part of a base, and is therefore called *basic water*. In the section on phosphorus (511, 512), will be found several examples, illustrating some of its properties. That it is entirely distinct from the water of crystalization may be shown by heating some crystals of the common phosphate of soda, which is composed of 1 eq. of phosphoric acid, 2 eq. of soda, and 25 eq. of water. When the temperature has risen to 212°, 24 equivalents of the water are readily expelled, but the 25th eq. is retained with such force, that a red heat is necessary to effect its complete separation. By the loss of the first 24 eq. of water, the crystaline form and texture of the salt are entirely destroyed, but the amorphous mass has still all the properties of the common phosphate; whereas by the loss of the 25th eq., an entirely new salt, the bibasic phosphate of soda, is produced.

806. The same thing is observed in the case of the common sulphate of zinc. The crystals of this substance are composed of 1 eq. of sulphuric acid, 1 eq. of oxide of zinc, and 7 eq. of water. When heated, 6 eq. of the water escape at 212°, but the 7th eq. is not expelled till the temperature

rises to 410°. Thus far this 7th eq. of water in the sulphate of zinc appears analogous to the 25th eq. in phosphate of soda: there is found this difference, that in the latter salt the equivalent of water is readily replaced by an equivalent of any base, while in the case of the sulphate of zinc, the equivalent of water is not affected by bases, but may be removed by anhydrous sulphates, which, by replacing it, form with sulphate of zinc, double salts. This water, therefore, not acting the part of a base, but entering into the constitution of the salt, is called *constitutional water.*

Salts in crystalizing frequently inclose mechanically within their texture particles of water, by the expansion of which, when heated, the salt is burst with a crackling noise into smaller fragments. This phenomenon is known by the name of *decrepitation.* Berzelius has correctly remarked that those crystals decrepitate most powerfully, such as the nitrates of baryta and oxide of lead, which contain no water of crystalization.

807. The atmospheric pressure is said to have considerable influence on the crystalization of salts. If, for example, a concentrated solution of sulphate of soda is made to boil briskly, and the flask which contains it is then tightly corked, while its upper part is full of vapor, the solution will cool down to the temperature of the air without crystalizing, and may in that state be preserved for months without change. Before removal of the cork, the liquid may often be briskly agitated without losing its fluidity; but on readmitting the air, crystalization commonly commences, and the whole becomes solid in the course of a few seconds. The admission of the air sometimes, indeed, fails in causing the effect; but it may be produced with certainty by agitation or the introduction of a solid body. The theory of this phenomenon is not very apparent; but that the mere pressure of the atmosphere does not produce the effect is evident from the fact that a mere film of oil upon the surface of the solution in the flask as effectually prevents crystalization as if it is tightly corked while hot. It has been suggested that the influence of the air may be ascribed to its uniting chemically with the water; and it is found that gases which are absorbed more freely than air, act more rapidly in producing crystalization.

The same quantity of water may hold several different salts in solution, provided they do not mutually decompose each other. The solvent power of water with respect to one salt is, indeed, sometimes increased by the presence of another, owing to combination taking place between the two salts.

Most salts produce cold during the act of solution, especially when they are dissolved rapidly and in large quantity. The greatest reduction of temperature is occasioned by those which contain water of crystalization.

808. The above "general remarks" on the subject of salts are in accordance with the opinions which have heretofore generally prevailed concern-

ing their nature and composition; but recently some new views on this important subject have begun to prevail, which, though they cannot be formally adopted, ought not to be entirely overlooked, even in an elementary work. These views are the more important, as they serve admirably to explain many facts in organic chemistry that before appeared anomalous.

809. By referring to the oxygen acids described in the preceding pages, it will be observed that they all, with the exception of the carbonic and chromic acids, in their free or *active* state, contain hydrogen, which has been considered as associated with oxygen in the form of water. Thus, sulphuric acid, or oil of vitriol (490), in its most concentrated state, is $2SO_3$, HO, while the common sulphuric acid is SO_3,HO. So nitric acid is NO_5, HO; and indeed it cannot exist separate from water, NO_5; and this is the case with a majority of known acids. Sulphuric and phosphoric acids may without question be obtained anhydrous, SO_3 and P_2O_5; but it is worthy of notice, that in this state *they do not possess the properties of these acids*, and acquire them only on the addition of water. The dry compound of sulphuric acid and ammonia, SO_3,NH_3, for instance, is not sulphate of ammonia, but a distinct compound. Moreover, these anhydrous acids unite with water with the greatest vehemence, and then assume their active characters.

810. Now, as the hydracids, as a matter of course, contain hydrogen, according to this view it is evident the two classes of oxygen and hydracids may be brought together in single class of hydracids, as having the most perfect analogy in properties. Letting X represent the acid-radical, which may be either simple or compound, the general formula for a hydracid will be X,H. In hydrochloric (542), hydriodic (569), and hydrosulphuric (496) acids, the acid-radical is simple, and X is represented respectively by Cl, I, and S; but in most of the acids of organic substances, the acid-radical is compound. In the hydrated oxygen acids which have been described in the preceding pages, and to which alone and not to the anhydrous acids this theory applies, the acid-radical X is always compound and always contains oxygen. Thus in hydrated sulphuric acid—as it is usually considered and represented by SO_3,HO,—X is represented by SO_4: and in common nitric acid, NO_5,HO, (as it is usually considered,) $X=NO_6$. The true formula for these acids on this theory are SO_4,H, and NO_6,H. Other examples might be adduced. Those acids which contain a single equivalent of hydrogen, are in general capable of uniting with a single equivalent of a base, and are therefore called monobasic; those that contain 2 equivalents of hydrogen combine with as many equivalents of base, and are called bibasic (302), while those that have 3 equivalents of hydrogen are tribasic. These acids, as a class, are called polybasic, and their general formula is X, Hn. Phosphoric acid is polybasic; it unites with water and other bases, forming monobasic, bibasic, and tribasic phosphates. The three states of the acid, or three phosphates of water, are written as follows:

	Old Theory.	*New Theory.*
Monobasic acid	P_2O_5,HO	P_2O_6,H.
Bibasic acid	P_2O_5,2HO	P_2O_7,H_2.
Tribasic acid	P_2O_5,3HO	P_2O_8,H_3.

811. But it is among the organic acids that we find the most numerous and striking examples of polybasic acids.

When one of these hydracids unites with a metallic oxide to form a salt, the hydrogen is simply replaced by the metal, and water is formed by the union of the hydrogen of the acid and the oxygen of the base. Consequently, acids may be viewed as the hydrogen salts of their radicals, and thus the acids and salts, in regard to their constitution, will form but one class.

812. A necessary consequence deducible from this theory is, that those oxides which most easily lose oxygen should most readily replace by their metal the hydrogen of the acid. This inference is found strictly in conformity with fact; the oxide of silver, being easily reduced, is capable of replacing with its silver all the hydrogen of several acids, while potassa or soda can replace by their metallic base only a part.

SECTION II.

ORDER I.—OXY-SALTS.

813. This order of salts includes no compound the acid or base of which does not contain oxygen. With the apparent exception of ammoniacal salts, both the acid and base of the salts described in this section are oxydized bodies. As each acid, with few exceptions, is capable of uniting with every alkaline base, and frequently in two or more proportions, it is manifest that the salts must constitute a very numerous class of bodies. It is necessary, on this account, to facilitate the study of them as much as possible by classification. They may be conveniently arranged by placing together those salts which contain either the same salifiable base or the same acid. It is not very material which principle of arrangement is adopted; but, on the whole, it is thought best to adopt the latter, especially since, in the description of the different oxides in the preceding pages, some account has been given of the characteristic features of their salts. We shall therefore describe the salts in families, placing together those which consist of the same acid united with the different salifiable bases. The salts of each family, in consequence of containing the same acid, possess certain characters in common, by which they may all be distinguished; and separate descriptions are therefore perhaps less needed than in almost any other class of bodies. In the following pages, in accordance with the plan previously pursued, a few salts only of the most practical importance will be selected for description.

814. After describing the neutral salts of each family, some of the more important *double salts* of the same family will be introduced. These may be composed of one acid and two bases, of two acids and one base, and of two different acids and two different bases. Most of the double salts hitherto examined consist of the same acid and two different bases.

815. The difference in the constitution of ammonia (432) and that of all other bases capable of uniting with oxy-acids, gives a peculiar interest to

its salts. Though this substance possesses all the characteristics of an alkali, even neutralizing the strongest acids, it is thought by Berzelius and others that it does not unite with them as ammonia, but as the oxide of a compound radical, which they call *ammonium*, composed of 1 equivalent of nitrogen and 4 equivalents of hydrogen, NH_4. When a current of electricity is passed through a solution of ammonia in contact with a portion of mercury as the negative electrode, the mercury is rapidly converted into a light porous substance, which has the lustre and all the characters of an amalgam. As soon as it is removed from the influence of the electric current, rapid decomposition ensues, mercury is reproduced, and hydrogen and ammoniacal gases evolved in the ratio of one volume of the former to two of the latter. The production of this compound is explained upon the supposition that ammonia NH_3, by uniting with an additional equivalent of hydrogen, forms a compound NH_4, which has the properties of a metal forming with mercury an amalgam, and its oxide NH^4, O, serving as the real radical to the ammoniacal salts, as above explained. This hypothesis is further confirmed by the fact that, in all the neutral salts of ammonia the quantity of water necessary to convert the ammonia into oxide of ammonium, is always present, nor can it be removed without the total decomposition of the salt. Anhydrous crystals of compounds of ammonia with the oxy-acids have indeed been obtained, but they do not possess the proper characters of salts (795), neither the acid nor alkali being present as such in the compound.

Sulphuric acid containing 3 equivalents of oxygen, the oxygen in the acid and base of the neutral protosulphates, will of course be in the ratio of 3 to 1; and if it should be entirely separated from both, a metallic protosulphuret would result.

SULPHATES.

816. The salts of sulphuric acid in solution may be detected by chloride of barium. A white precipitate, sulphate of baryta, invariably subsides, which is insoluble in acids and alkalies, a character by which the presence of sulphuric acid, whether free or combined, may always be recognized. An insoluble sulphate, such as sulphate of baryta or strontia, may be detected by mixing it, in fine powder, with three times its weight of carbonate of potassa or soda, and exposing the mixture in a platinum crucible for half an hour to a red heat. Double decomposition ensues, and a sulphate of the alkali used is formed, which, by proper precautions, may be detected by chloride of barium, as above described.

817. Several sulphates exist in nature, but the only ones which are abundant are the sulphates of lime and baryta. All of them may be formed by the action of sulphuric acid on the metals themselves, on the metallic oxides or their carbonates, or by way of double decomposition.

The solubility of the sulphates is very variable. There are six only which may be regarded as really insoluble; namely, the sulphates of baryta, and of the oxides of tin, antimony, bismuth, lead, and mercury. The sparingly soluble sulphates are those of strontia, lime, zirconia, yttria, and of the oxides of cerium and silver. All the others are soluble in water.

818. All the sulphates, those of potassa, soda, lithia, baryta, strontia, and lime excepted, are decomposed by a white heat. One part of the sulphuric acid of the decomposed sulphate escapes unchanged, and another portion is resolved into sulphurous acid and oxygen. Those which are easily decomposed by heat, such as sulphate of oxide of iron, yield the largest quantity of undecomposed sulphuric acid.

819. When a sulphate, mixed with carbonaceous matter, is ignited, the oxygen both of the acid and of the oxide unites with carbon, carbonic acid is disengaged, and a metallic sulphuret remains. A similar change is produced by hydrogen gas at a red heat, with formation of water and frequently of some hydrosulphuric acid. In some instances the hydrogen entirely deprives the metal of its sulphur.

820. The following table represents the composition of some of the principal sulphates, both anhydrous, and with water of crystalization when they crystalize with water.

Names.	*Base.*	*Acid.*	*Equiv.*	*Symbols.*
Sulphate of potassa	1 eq. +	1 eq.	87.25	KO,SO_3
Bisulphate of potassa	1 eq. +	2 eq.	127.35	$KO,2SO_3$
Do. do. in crystals with	1 eq. of water		136.35	
Sulphate of soda	1 eq. +	1 eq.	71.4	NaO,SO_3
Do. do. in crystals with	10 eq. of water		161.4	
Bisulphate of soda	1 eq. +	2 eq.	111.5	$NaO,2SO_3$
Do. do. in crystals with	4 eq. of water		147.5	
Sulphate of oxide of ammonium	1 eq. +	1 eq.	66.25	NH_4O,SO_3
Do. do. in crystals with	1 eq. of water		75.25	
Sulphate of baryta	1 eq. +	1 eq.	116.8	BaO,SO^3
Sulphate of strontia	1 eq. +	1 eq.	91.9	SrO,SO_3
Sulphate of lime	1 eq. +	1 eq.	68.6	CaO,SO_3
Do. do. as gypsum with	2 eq. of water		86.6	
Sulphate of magnesia	1 eq. +	1 eq.	60.8	MgO,SO_3
Do. do. in crystals with	7 eq. of water		123.8	
Sulphate of alumina	1 eq. +	1 eq.	91.5	Al_2O_3,SO_3
Do. do. in crystals with	9 eq. of water		172.5	
Sulphate of protoxide of manganese	1 eq. +	1 eq.	75.8	MnO,SO_3
Do. do. in crystals with	5 eq. of water		120.8	
Sulphate of protoxide of iron	1 eq. +	1 eq.	76.1	FeO,SO_3
Do. do. in crystals with	6 eq. of water		130.1	
Sulphate of protoxide of zinc	1 eq. +	1 eq.	80.4	ZnO,SO_3
Do. do. in crystals with	7 eq. of water		143.4	
Sulphate of protoxide of copper	1 eq. +	1 eq.	79.7	CuO,SO_3
Disulphate of protoxide of copper	2 eq. +	1 eq.	119.3	$2CuO,SO_3$
Sulphate of protoxide of mercury	1 eq. +	1 eq.	250.1	HgO,SO_3
Bisulphate of peroxide of mercury	1 eq. +	2 eq.	298.2	$HgO_2,2SO_3$
Sulphate of oxide of silver	1 eq. +	1 eq.	156.1	AgO,SO_3

DOUBLE SULPHATES.

Sulphate of potassa and alumina....	Sulphate of potassa 1 eq. Tersulphuret alum. 1 eq.	258.95	KO,SO_3 + $Al_2O_3,3SO_3$
Do. do.	with 24 eq. of water......	474.95	
Sulphate of soda and alumina....	Sulphate of soda...1 eq. Tersulphate alum .1 eq.	243.1	NaO,SO_3 + $Al_2O_3,3SO_3$
Do. do.	with 26 eq. of water......	477.1	

821. *Sulphate of Potassa.*—This salt is easily prepared artificially by neutralizing carbonate of potassa with sulphuric acid; and it is procured abundantly by neutralizing with carbonate of potassa the residue of the operation for preparing nitric acid (423). Its taste is saline and bitter.. It generally crystalizes in six-sided prisms, bounded by pyramids with six sides, the size of which is said to be much increased by the presence of a little carbonate of potassa. Its primary form is a rhombic octohedron, and it is isomorphous with chromate and seleniate of potassa. The crystals contain no water of crystalization, and suffer no change by exposure to the air. They decrepitate when heated, and enter into fusion at a red heat. They require 16 times their weight of water at 60°, and 5 of boiling water for solution.

822. *Bisulphate of Potassa* is easily formed by exposing the neutral sulphate with half its weight of strong sulphuric acid to a heat just below redness, in a platinum crucible, until acid fumes cease to escape. The primary form of its crystals is a right rhombic prism. It has a strong sour taste, and reddens litmus paper. According to Graham it is to be considered a double sulphate of potassa and water. It is much more soluble than the neutral sulphate, requiring for solution only twice its weight of water at 60°, and less than an equal weight at 212°. It is resolved by heat into sulphuric acid and the neutral sulphate.

823. *Sulphate of Soda.*—This compound, commonly called *Glauber's Salt,* is occasionally met with on the surface of the earth, and is frequently contained in mineral springs. It was discovered by Glauber, from whom it received its name, although he himself called it *sal mirabile.*

It may be made by the direct action of sulphuric acid on carbonate of soda, and it is procured in large quantity as a residue in the process for forming hydrochloric acid and chlorine (542).

824. Sulphate of soda has a cooling, saline, and bitter taste. It commonly yields four and six-sided prismatic crystals, but its primary form is a rhombic octohedron. Its crystals effloresce rapidly when exposed to the air, losing the whole of their water. When heated they readily undergo the watery fusion. At 32°, 100 parts of water dissolve 12 parts of the crystals, 48 parts at 64.5°, 100 parts at 77°, 270 at 89.5°, and 322 at 91.5°. On increasing the heat beyond this point, a portion of the salt is deposited, being less soluble than at 91.5°. If a solution saturated at 91.5° is evaporated at a higher temperature, the salt is deposited in opaque anhydrous prisms, the primary form of

which is a rhombic octohedron. Its specific gravity in this state is 2.46.

Bisulphate of Soda may be formed in the same manner as the analogous salt of potassa (822).

825. *Sulphate of Oxide of Ammonium—Sulphate of Ammonia.*—This salt is easily formed by neutralizing carbonate of ammonia with dilute sulphuric acid; and it is contained in considerable quantity in the soot from coal.

It is important as a source of the hydrochlorate of ammonia, which is obtained by sublimation from a mixture of sulphate of ammonia and common salt. It is sometimes found native in small quantities in volcanic countries.

826. *Sulphate of Baryta.*—Native sulphate of baryta, commonly called *heavy spar*, occurs abundantly, chiefly massive, but sometimes in anhydrous crystals, the form of which is variable, being sometimes prismatic and sometimes tabular, deducible from a right rhombic prism. Its density is about 4.4. It is one of the most insoluble salts known, and of late has been considerably used by painters as a substitute for white lead.

827. *Sulphate of Strontia*, the *Celestine* of mineralogists, very much resembles the above, and is sometimes mistaken for it. Its specific gravity is 3.86.

828. *Sulphate of Lime.*—This salt occurs abundantly as a natural production. The mineral called *anhydrite* is anhydrous sulphate of lime; and all the varieties of *gypsum* are composed of the same salt, united with water. The pure crystalized specimens of gypsum are sometimes called *selenite;* and the white compact variety is employed in statuary under the name of *alabaster.* The crystals are generally flattened prisms, the primary form of which is a right rhombic prism.

Gypsum contains 2 equivalents of water, which are readily expelled by a temperature a little below 300°, and it then crumbles into a fine powder. If this powder is mixed with water, the 2 equivalents are again absorbed and gypsum is reproduced, and the mass rapidly becomes dry and hard. On this property is founded the art of casting in plaster, and the formation of the various kinds of *stucco,* in which a solution of glue or gum is often used in place of pure water. If in baking the gypsum is heated above 300°, its nature is changed, and anhydrite is formed, which will not combine with water so as "to set."

Solutions of caustic potassa, or several of its salts, as the carbonate, sulphate, or silicate, when mixed with the raw gypsum finely pulverized, also produce immediate and perfect solidification.

This salt, under the name of *plaster*, or *Plaster of Paris*, is largely used in agriculture. It is slightly soluble in water, requiring for solution about 450 or 500 times its weight of water. Dissolved in this minute quantity with other salts in well or spring-water, it communicates to it the property called *hardness.*

829. *Sulphate of Magnesia.*—This sulphate, generally known by the name of *Epsom salt*, is frequently contained in mineral springs, as at Epsom, in England. It may be made directly, by neutralizing dilute sulphuric acid with carbonate of magnesia; but it is procured for the purposes of commerce by the action of dilute sulphuric acid on magnesian limestone, which is a native carbonate of lime and magnesia.

Its taste is saline, bitter, and nauseous. It may readily be distinguished from sulphate of soda by the form of its crystals or by pouring into a solution of it, a little caustic potassa, which will cause a white precipitate. In sulphate of soda no such effect will be produced.

830. *Sulphates of Iron.*—*Sulphate of the Protoxide*, commonly called *green vitriol*, is formed by the action of dilute sulphuric acid on metallic iron, or by exposing protosulphuret of iron, in fragments, to the combined agency of air and moisture. The salt has a strong, styptic, inky taste. It is insoluble in alcohol, but soluble in two parts of cold, and in three-fourths of its weight of boiling water. It occurs in right rhombic prisms, which are transparent, and of a pale green tint; but when its water of crystalization is expelled, it is of a dirty white color.

It is used for various purposes in the arts under the name of *copperas* or *green vitriol*. It is employed in the manufacture of fuming sulphuric acid. It contains a large quantity of water of crystalization, which gradually escapes in the open air, and the crystals crumble to powder.

Much of the green vitriol of commerce is formed by exposing the native sulphuret of iron to the action of the weather, by which both the sulphur and iron are oxydized, to form the sulphate of iron.

When this salt is heated it parts first with its water, and at a full red heat, with its sulphuric acid, a portion of which is decomposed into sulphurous acid and oxygen, and the rest passes off unchanged. By the oxygen of the decomposed acid the iron is peroxydized, forming the substance used in the arts as a polishing powder, under the names of *rouge* and *colcothar*.

The *tersulphate of the sesquioxide* is not used in the arts.

831. *Sulphate of Zinc.*—This is the *white vitriol* of commerce. It may readily be formed by the action of dilute sulphuric acid upon metallic zinc. It is used in medicine and in the arts.

832. *Sulphate of Copper.*—Sulphate of the red oxide of copper has not been obtained in a separate state. The sulphate of the black, or protoxide, *blue vitriol*, employed by surgeons as an escharotic and astringent, may be prepared by roasting the native sulphuret; but it is more generally made by directly dissolving the protoxide in dilute sulphuric acid, and crystalizing by evaporation. This salt forms crystals of a blue color, the primary form of which is the oblique rhomboidal

prism. It is soluble in about four of cold, and in two parts of boiling water. It is isomorphous with sulphate of protoxide of manganese.

When pure potassa is added to a solution of the sulphate of protoxide of copper, in a quantity insufficient for separating the whole of the acid, a pale bluish-green precipitate, the disulphate, is thrown down.

Sulphate of protoxide of copper and ammonia is generated by dropping pure ammonia into a solution of the sulphate, until the sub-salt at first thrown down is nearly all dissolved. It forms a dark blue solution, from which, when concentrated, crystals are deposited by the addition of alcohol. It may be formed also by rubbing briskly in a mortar two parts of crystalized sulphate of protoxide of copper with three parts of carbonate of ammonia, until the mixture acquires a uniform deep blue color. Carbonic acid gas is disengaged with effervescence during the operation, and the mass becomes moist, owing to the water of the blue vitriol being set free.

This compound, which is the *ammoniuret of copper* of the Pharmacopœia, contains sulphuric acid, protoxide of copper, and ammonia; but its precise nature has not been determined in a satisfactory manner. It parts gradually with ammonia by exposure to the air.

833. *Sulphates of Mercury.*—Sulphate of the protoxide of mercury is formed when two parts of mercury are gently heated with three parts of strong sulphuric acid; but if strong heat is employed, so as to excite brisk effervescence, and the mixture brought to dryness, a bisulphate of the peroxide results. When this bisulphate is thrown into hot water it is decomposed and a yellow basic sulphate is formed, formerly called *turpeth mineral*, $3HgO,SO_3$.

DOUBLE SULPHATES.

Sulphate of soda and lime is the *glauberite* of mineralogists. It is found native.

834. *Sulphate of Potassa and Alumina.—Alum.*—This well-known substance is usually prepared from alum-slate, an argillaceous slaty rock, highly charged with iron pyrites. On heating this rock the sulphuret of iron is oxydized, the resulting sulphuric acid unites with alumina and potassa present in the slate, and the alum is dissolved out by water. By frequent crystalization it is purified from the oxide of iron, which obstinately adheres to it. In Italy it is prepared from *alum-stone*, which occurs at Tolfa, near Rome, and in most volcanic districts, being formed apparently by the action of sulphuric acid vapors on felspathic rocks. The materials of the alum exist in the stone ready formed; and they are extracted by gently heating the rock, exposing it for a time to the air, and lixiviation. The alum from this source has been long prized, in

consequence of being quite free from iron. In both of these processes the alkali contained in the alum-rock is inadequate for uniting with the sulphate of alumina which is obtained, and hence a salt of potassa must be added.

Alum has a sweetish, astringent taste, and reddens litmus paper. It is soluble in five parts of water at 60°, and in little more than its own weight of boiling water. It crystalizes readily in octohedrons, or in segments of the octohedron, and the crystals contain 24 atoms or almost 50 per cent. of water of crystalization. On being exposed to heat, they froth up remarkably, and part with all the water, forming anhydrous alum, the *Alumen Ustum* of the Pharmacopœia. At a full red heat the alumina is deprived of its acid.

This salt is much used in medicine and in the arts, especially in dyeing and calico-printing. Ignited with charcoal, it forms a spontaneously inflammable compound, which has long been known under the name of *Homberg's Pyrophorus*.

835. *Iron Alum.*—This compound very much resembles common alum, but often, though not always, it has a pink tint. It is formed by mixing sulphate of potassa with tersulphate of peroxide of iron, and crystalizing by spontaneous evaporation. It differs from common alum in constitution by containing peroxide of iron instead of alumina, with which this oxide is isomorphous. Ammonia may also replace the potassa, producing a similar double salt.

836. *Chromium Alum.*—The tersulphate of the sesquioxide of chromium forms with potassa and ammonia double salts, which are exactly similar in form and composition to the preceding varieties of alum. Their crystals are black by reflected, but red by transmitted light.

837. *Manganese Alum.*—This alum is formed by the replacement of alumina in common alum by the sesquioxide of manganese, with which it is isomorphous. It is made with some difficulty.

838. *Basic Alum.—Cubical Alum.*—This substance, which is preferred as a mordant to ordinary alum, is prepared by adding carbonate of potassa to a solution of alum as long as the precipitate which first forms is redissolved by agitation. It crystalizes in cubes, which have no acid reaction, Its composition is $Al_2O_3,2SO_3+KO,SO_3$.

NITRATES.

839. THE nitrates may be prepared by the action of nitric acid on metals, on the salifiable bases themselves, or on carbonates. As nitric acid forms soluble salts with all alkaline bases, the acid of the nitrate cannot be precipitated by any reagent.

All the nitrates are decomposed, without exception, by a high temperature; but the changes which ensue are modified by the nature of the oxide.

From some of them, most of the acid passes off at comparatively low temperatures unchanged, but with others the case is different, the acid being decomposed. Nitrate of potassa, for instance, when heated, as in the process for procuring oxygen, is decomposed and reduced to a nitrite of potassa, giving up of course one equivalent of the oxygen of the acid. As the temperature is raised, still other complicated changes are produced, the binoxide and protoxide of nitrogen being given off, mixed with oxygen, till at length the peroxide of potassium alone remains in the retort.

When nitrate of potassa in fine powder is mixed with a combustible substance, and thrown into a red-hot crucible, rapid combustion is produced, called *deflagration.*

All the neutral nitrates of the fixed alkalies and alkaline earths, together with most of the neutral nitrates of the common metals, are composed of one equivalent of nitric acid, and one equivalent of a protoxide. Consequently, the oxygen of the oxide and acid in all such salts must be in the ratio of 1 to 5.

840. The composition of some of the principal nitrates is exhibited in the following table:—

Names.	*Base.*	*Acid.*	*Equiv.*	*Symbols.*
Nitrate of potassa	1 eq.	+ 1 eq.	101.3	KO,NO_5
——— soda	1 eq.	+ 1 eq.	85.45	NaO,NO_5
——— oxide of ammonium	1 eq.	+ 1 eq.	80.3	H_4NO,NO_5
——— baryta	1 eq.	+ 1 eq.	130.85	BaO,NO_5
——— strontia	1 eq.	+ 1 eq.	105.95	SrO,NO_5
Do. do. in prisms with 5 eq. of water			150.95	
Nitrate of lime	1 eq.	+ 1 eq.	82.65	CaO,NO_5
——— magnesia	1 eq.	+ 1 eq.	74.85	MgO,NO_5
——— protoxide of copper	1 eq.	+ 1 eq.	93.75	CuO,NO_5
Do. do. in prisms with 7 eq. of water			156.75	
Nitrate of protoxide of lead	1 eq.	+ 1 eq.	165.75	PbO,NO_5
Dinitrate of do.	2 eq.	+ 1 eq.	277.35	$2PbO,NO_5$
Nitrate of protoxide of mercury	1 eq.	+ 1 eq.	264.15	HgO,NO_5
Do. do. in crystals with 2 eq. of water			282.15	
Nitrate of peroxide of mercury	1 eq.	+ 1 eq.	272.15	HgO_2,NO_5
Dinitrate of do.	2 eq.	+ 1 eq.	490.15	$2HgO_2,NO_5$
Nitrate of oxide of silver	1 eq.	+ 1 eq.	170.15	AgO,NO_5

841. *Nitrate of Potassa.*—This salt, the *nitre* or *saltpetre* of commerce, is generated spontaneously in the soil, and crystalizes upon its surface, in several parts of the world, and especially in the East Indies, whence the greater part of the nitre used in Britain is derived.

In this country it is formed by decomposing the nitrate of lime, which is found abundantly in caverns in some of the western states, by the carbonate of potassa which is contained in wood-ashes. In France and Germany it is prepared in artificial *nitre-beds*. These consist of refuse animal and vegetable substances undergoing putrefaction, mixed with calcareous and other earths. It has been ascertained that the oxygen of the atmosphere unites with the nitrogen, as it is gradually liberated from the animal substances, forming nitric acid, which immediately combines with the lime and other earths that may be present. By lixivating the earthy matters with water, and mixing the nitrates of lime, magnesia, &c., thus obtained, with carbonate of potassa, the earthy bases are precipitated, and nitrate of potassa obtained in solution, which, by evaporation, yields the salt in crystals. In France, much of this salt is obtained by lixiviation from certain kinds of plaster of old houses, where nitrate of lime is gradually generated.

Nitrate of potassa is a colorless salt, which crystalizes readily in six-sided prisms. Its taste is saline, accompanied with an impression of coolness. It requires for solution seven parts of water at 60°, and its own weight of boiling water. It contains no water of crystalization, but its crystals are never quite free from water lodged mechanically within them. At 616° it undergoes the igneous fusion, and, like all the nitrates, is decomposed by a red heat.

Nitre is chiefly employed in chemistry as an oxydizing agent, and in the formation of nitric acid. Its chief use in the arts is in making gunpowder, which is a mixture of nitre, charcoal, and sulphur, in the ratio of about 6 parts of nitre to 1 of each of the other substances. The proportions, however, are not always the same. The nitre, by its decomposition, furnishes oxygen (365), which combines the carbon, the sulphur at the same time uniting with the potassa. The action of gunpowder depends upon its generating, when decomposed, a large quantity of gaseous matter at a high temperature. The gases are chiefly nitrogen and carbonic acid, which at the moment of explosion occupy more than 1000 times the volume of the powder from which they are formed. The formation of the gases is not instantaneous, but occupies a certain time, and the ball is forced from the gun with a velocity due to the ultimate effect of the whole. This salt is also used in the manufacture of nitric acid (423). It is a powerful antiseptic, and is therefore used with common salt in the preservation of meat and other substances.

Nitre has sometimes been mistaken for sulphate of soda, but may readily be distinguished from it by its deflagrating when thrown upon burning charcoal.

842. *Nitrate of Soda* resembles nitrate of potassa in many of its properties, but cannot be substituted for it in the manufacture of gunpowder. It may be used in the manufacture of nitric acid.

843. *Nitrate of Baryta.*—This salt is sometimes used as a reagent, and for preparing pure baryta. It is easily prepared by digesting the native

carbonate, reduced to powder, in nitric acid, diluted with eight or ten times its weight of water. The salt crystalizes readily by evaporation in transparent anhydrous octohedrons, and is very apt to decrepitate by heat unless previously reduced to powder. It requires 12 parts of water at 60° and 3 or 4 of boiling water for solution, but is insoluble in alcohol. It undergoes the igneous fusion in the fire before being decomposed.

844. *Nitrate of Strontia.*—This salt may be made from strontianite in the same manner as the foregoing compound, to which it is exceedingly analogous. It commonly crystalizes in anhydrous octohedrons, which undergo no change in a moderately dry atmosphere, and are insoluble in alcohol; but sometimes it contains 30 per cent. of water of crystalization, and then assumes the form of a prism with ten sides and two summits.

845. *Nitrates of Lime and Magnesia.*—These salts crystalize in hydrated prisms when their solutions are concentrated to the consistence of syrup; but the quantity of water which they contain is not ascertained. They deliquesce rapidly in the air, are very soluble in water, and are dissolved by alcohol, the nitrate of lime more freely than nitrate of magnesia.

Nitrate of lime is found native in great abundance in caverns in Kentucky and other southwestern states (841).

846. *Nitrate of Protoxide of Copper.*—This salt is prepared by the action of nitric acid on copper. It crystalizes, though with some difficulty, in prisms of a deep blue color, which are very soluble in water and alcohol, and deliquesce on exposure to the air. When heated to redness it yields pure oxide of copper.

847. *Nitrate of Protoxide of Lead.*—This salt is formed by digesting litharge in dilute nitric acid, and crystalizes readily in octohedrons which are anhydrous and almost always opaque. It has an acid reaction, but is neutral in composition.

848. *Nitrates of Mercury.*—There are several nitrates of mercury, but the *protonitrate* and the *pernitrate* are the most important. The first is conveniently formed by digesting mercury in nitric acid, diluted with three or four parts of water, until the acid is saturated, and then allowing the solution to evaporate spontaneously in an open vessel. The solution always contains at first some nitrate of the peroxide, but if metallic mercury is left in the liquid, a pure protonitrate is gradually deposited.

When mercury is heated in an excess of strong nitric acid, it is dissolved with brisk effervescence, owing to the escape of binoxide of nitrogen, and transparent prismatic crystals of the *pernitrate* are deposited as the solution cools.

849. *Nitrate of Silver.*—Silver is readily oxydized and dissolved by nitric acid diluted with two or three times its weight of water, forming a solution which yields transparent tabular crystals by evaporation. These crystals, which are anhydrous, undergo the igneous fusion at 426°, and yield a crystaline mass in cooling; but when the temperature reaches 600° or 700° complete decomposition ensues, the acid being resolved into oxygen and nitrous acid, while metallic silver is left. When liquefied by heat, and received in small cylindrical moulds, it forms the *lapis infernalis* or *lunar caustic,* employed by surgeons as a cautery. The nitric acid appears to be the agent which destroys the animal texture, and the black stain

is owing to the separation of oxide of silver. It is sometimes employed for giving a black color to the hair, and is the basis of indelible ink, used for marking linen.

The pure nitrate is colorless and transparent, and does not deliquesce by exposure to the air; but common lunar caustic is dark and opaque, and dissolves imperfectly in water, owing to some of the nitrate being decomposed during its preparation. It is often adulterated with nitre, which is melted with it. The pure salt is soluble in its own weight of cold, and in half its weight of hot water. It dissolves also in four times its weight of alcohol. Its aqueous solution, if preserved in clean glass vessels, undergoes little or no change even in the direct solar rays; but when exposed to light, rspecially to sunshine, in contact with paper, the skin, or any organic substance, a black stain is quickly produced, owing to decomposition of the salt and reduction of its oxide to the metallic state.

CHLORATES.

850. The salts of chloric acid are very analogous to the nitrates. As the chlorates of the alkalies, alkaline earths, and most of the common metals are composed of one equivalent of chloric acid and one equivalent of a protoxide, it follows that the oxygen of the former to that of the latter is in the ratio of 1 to 5. The chlorates are decomposed by a red heat, nearly all of them being converted into metallic chlorides, with evolution of pure oxygen gas. They deflagrate with inflammable substances with greater violence than nitrates, yielding oxygen with such facility that an explosion is produced by slight causes. Thus a mixture of sulphur with three times its weight of chlorate of potassa explodes when struck between two hard surfaces. With charcoal and the sulphurets of arsenic and antimony this salt forms similar explosive mixtures; and with phosphorus it detonates violently by percussion. One of the mixtures employed in the percussion locks for guns consists of sulphur and chlorate of potassa, with which a little charcoal or gunpowder is mixed; but as the use of these materials is found corrosive to the lock, fulminating mercury is now generally preferred.

All the chlorates hitherto examined are soluble in water, excepting the chlorate of protoxide of mercury, which is of sparing solubility. These salts are distinguished by the action of strong hydrochloric and sulphuric acids, the former of which occasions the disengagement of chlorine and protoxide of chlorine, and the latter peroxide of chlorine.

None of the chlorates are found native, and the only one that requires particular description is the

851. *Chlorate of Potassa.*—This salt, formerly called *oxymuriate* or *hyper-oxymuriate of potash*, is colorless, and crystalizes in four and six-sided scales of a pearly lustre. Its primary

form is an oblique rhombic prism. It is soluble in sixteen times its weight of water at 60°, and in two and a half of boiling water. It is quite anhydrous, and when exposed to a temperature of 400° or 500° undergoes the igneous fusion. On increasing the heat almost to redness, effervescence ensues, and pure oxygen gas is disengaged (365). It can bear a heat of 600° without decomposition.

Chlorate of potassa is made by transmitting chlorine gas through a concentrated solution of pure potassa, until the alkali is completely neutralized. The solution, which, after being boiled for a few minutes, contains nothing but chloride of potassium and chlorate of potassa, is gently evaporated till a pellicle forms upon its surface, and is then allowed to cool. The greater part of the chlorate crystalizes, while the chloride remains in solution. The crystals, after being washed with cold water, may be purified by a second crystalization.

This salt has been much used in the manufacture of the Lucifer matches. It yields its oxygen with the greatest readiness, and explodes when mixed with any combustible, as phosphorus, arsenic, or sulphur, and struck violently with a hammer. Substituted for nitrate of potassa in gunpowder, it answers well for many purposes, but the manufacture is so extremely dangerous that it is not now practised.

HYPOCHLORITES.

852. *Hypochlorite of Lime.*—The hypochlorites are produced by the action of chlorine gas on the salifiable bases (538). The most important of them is the hypochlorite of lime, the well-known *bleaching salt*, which has usually been described as the chloride of lime. It is prepared for commercial purposes by exposing thin strata of recently-slaked lime in fine powder to an atmosphere of chlorine. The gas is absorbed in large quantity, and chloride of calcium and hypochlorite of lime are produced in equivalent proportions.

It is a dry white powder, which smells faintly of chlorine, and has a strong taste. It dissolves partially in water, and the solution possesses powerful bleaching properties, and contains both chlorine and lime; while the undissolved portion is hydrate of lime, retaining a small quantity of chlorine. The aqueous solution, when exposed to the atmosphere, is gradually decomposed; chlorine is set free, and carbonate of lime generated. It is also decomposed by a strong heat: at first chlorine is evolved; but pure oxygen is afterwards disengaged, and chloride of calcium remains in the retort.

853. There is some difference of opinion with regard to the true constitution of this compound, but it is believed to be in accordance with the name given above. The bleaching salt of commerce always contains more or less hydrate of lime

mixed with it, as the result of the peculiar manner of manufacturing it.

This substance, in consequence of the ready method it affords of preparing chlorine (535), is extensively used in the arts and in medicine.

The relative value of different specimens of bleaching salt may be determined by ascertaining the comparative quantities of pure indigo they are capable of bleaching.

Hypochlorite of Soda.—This is the *disinfecting liquor of Labaraqué*, sometimes also called *chloride of soda.* It is prepared by passing a current of chlorine gas through a solution of carbonate of soda, as long as chlorine is absorbed, but no carbonic acid evolved. Its use is much the same as that of the compound last described.

PHOSPHATES.

854. As phosphoric acid is polybasic, we shall of course expect to find formed from it corresponding salts. They are the monobasic, the bibasic, and the tribasic phosphates. The bibasic phosphates, as the name implies, contain 2 equivalents of base united with 1 eq. of acid, but of these 2 eq. of base 1 eq. may be water and the other belong to some fixed base. So in the tribasic phosphates, there may be 1 or 2 eq. of fixed base, the rest in either case being water.

855. A few only of the phosphates will be here described, the composition of which will be seen from the following table:

Names.	*Base.*	*Acid.*	*Equiv.*	*Symbols.*
Tribasic phosphate of soda	3 eq.	+ 1 eq.	165.33	$3NaO,P_2O_5$
Do. do. in crystals with 24 eq. of water			381.3	
Do. do.	soda 2 eq. water 1 eq.	+ 1 eq.	143.	$2NaO,HO,P_2O_5$
Do. do.	soda 1 eq. water 2 eq.	+ 1 eq.	120.7	$NaO,2HO,P_2O_5$
Tribasic phos. of soda, ox. of ammon. and basic water	soda 1 eq. ox. ammon 1 eq. water 1 eq.	+ 1 eq.	137.85	NaO,H_4NO,HO,P_2O_5
Bibasic phosphate of soda	2 eq. soda	+ 1 eq.	134.0	$2NaO,P_2O_5$
Do. do.	soda 1 eq. water 1 eq.	+ 1 eq.	111.7	NaO,HO,P_2O_5
Monobasic phosphate of soda	1 eq. soda	+ 1 eq.	102.7	NaO,P_2O_5

856. *Tribasic Phosphate of Soda.*—This salt is made by adding pure soda to a solution of the succeeding compound until the liquid feels soapy to the fingers, an excess of soda not being injurious. The liquid is then evaporated until a pellicle appears, and the crystals which form on cooling are quickly redissolved in water and recrystalized.

It crystalizes in colorless six-sided slender prisms, which have a strong alkaline taste and reaction, require 5 times their weight of water at 60°, and still less of hot water, for solution, and at 170° fuse in their water of crystalization. They may be exposed to a red heat without losing the characters of a phosphate. The feeblest acids deprive the salt of one-third of its soda.

The common phosphate of soda of the shops is a tribasic phosphate, but 1 eq. of its base is water. It is manufactured on a large scale by neutralizing with carbonate of soda the acid phosphate of lime procured by the action of sulphuric acid on burned bones (504). It is generally described as the neutral phosphate of soda, and for distinction's sake is sometimes termed *rhombic phosphate*, from its crystals having the form of oblique rhombic prisms.

A third tribasic phosphate of soda is the salt commonly called *biphosphate of soda*, or *acid triphosphate of soda and water*, from its acid reaction. It contains 1 eq. of soda and 2 eq. of water, and may be formed by adding phosphoric acid to a solution of carbonate of soda, or to either of the preceding phosphates, until it ceases to give a precipitate with chloride of barium. Being very soluble in water, the solution must be concentrated in order that it may crystalize.

Heated to 400° this salt parts with half its basic water, and becomes a bibasic phosphate of soda, containing for its base a single equivalent of soda and water (855), but at a red heat it parts with all its water, and is converted into monobasic phosphate of soda.

All these three varieties of phosphate of soda give with the nitrate of silver a yellow precipitate (514) of tribasic phosphate of silver.

857. *Tribasic Phosphate of Soda, Oxide of Ammonium, and Basic Water.*—This salt is easily prepared by mixing together one equivalent of hydrochlorate of ammonia and two equivalents of the rhombic phosphate of soda, each being previously dissolved in a small quantity of water. As the liquid cools, prismatic crystals of the double phosphate are deposited, while chloride of sodium remains in solution. Their primary form is an oblique rhombic prism. This salt has been long known by the name of *microcosmic salt*, and is much employed as a flux in experiments with the blowpipe. When heated, it parts with its water and ammonia, and a very fusible metaphosphate of soda remains.

858. *Bibasic Phosphate of Soda.*—This salt is formed by heating the common phosphate of soda ($2NaO,HO,P_2O_5$) to redness (856); both the water of crystalization and the basic water are expelled, and with nitrate of silver a white precipitate, the bibasic phosphate, is formed, $2NaO,P_2O_5$, which by solution in water does not recombine with basic water. Another bibasic phosphate contains one equivalent of basic water, being composed thus, NaO,HO,P_2O_5.

859. *Monobasic Phosphate of Soda.*—Monobasic phosphate of soda, NaO, P_2O_5, may be formed by heating to redness either the variety of bibasic salt last mentioned, or the acid tribasic phosphate, $NaO, 2HO, P_2O_5$, to expel all their basic water. It forms with nitrate of silver a white precipi-

tate, which remains in flakes, unlike the white precipitate formed by the bibasic (858) phosphate.

860. *Tribasic Phosphate of Lime.*—This salt, often called *bone phosphate*, constitutes the chief part of the solid or inorganic portion of the bones of animals, mixed only with small portions of carbonate and sulphate of lime and fluoride of calcium. It is composed of 8 equivalents of lime united with 3 equivalents of acid; but is probably a compound of the two varieties of phosphate of lime $2(3CaO,P_2O_5)$, $2CaO,HO,P_2O_5$, each of which may be obtained separately.

The mineral called *apatite*, which is found in hexagonal prisms of a beautiful green color, is composed chiefly of tribasic phosphate of lime.

ARSENIATES.

861. ARSENIC acid resembles phosphoric acid in many of its properties, particularly in its strong tendency to form tribasic arseniates.

Many of the arseniates bear a red heat without decomposition, or being otherwise modified in their characters; but they are all decomposed, when heated to redness, along with charcoal, metallic arsenic being set at liberty. The arseniates of the fixed alkalies and alkaline earths require a rather high temperature for reduction; while the arseniates of the second class of metals, as of lead and copper, are easily reduced in a glass tube by means of a spirit-lamp, without danger of melting the glass.

Like the tribasic phosphates, these salts may contain either 1 or 2 eq. of water in connection with a fixed base. So also those that contain 2 eq. of basic water, like the corresponding phosphates, have an acid reaction, and were formerly considered as biarseniates.

The three tribasic arseniates of soda are composed as follows:

Names.	*Base.*	*Acid.*	*Equiv.*	*Symbols.*
Tribasic arseniate of soda	3 eq.	+ 1 eq.	209.3	$3NaO,AsO_5$
Do. do.	soda 2 eq. water 1 eq.	+ 1 eq.	187.	$2NaO,HO,As_2O_5$
Do. do.	soda 1 eq. water 2 eq.	+ 1 eq.	164.7	$NaO,2HO,As_2O_5$

No further description of these salts is necessary.

862. Tribasic arseniate of lime is sometimes found native, and is called *pharmacolite* by mineralogists. The tribasic arseniate of lime is sometimes found to replace the corresponding phosphate of lime in the bones of animals.

ARSENITES.

863. THE arsenites are little known. One or two only are seen in common, as the arsenite of potassa and of oxide of copper; the former of which is the active principle of *Fowler's arsenical solution*, and the latter is used as a pigment.

The common names for arsenite of copper is *Scheele's green*. It is prepared on a large scale by precipitation from a solution of sulphate of copper and a mixture of arsenious acid and pure carbonate of potassa. Another green pigment, called *emerald green*, is a definite compound of acetate of copper and the arsenite.

CHROMATES.

864. The salts of chromic acid are distinguished for their beautiful colors, most of them being either yellow or red, the latter color predominating when the acid is in excess. They may be known chemically by the following character. On boiling a chromate in hydrochloric acid mixed with alcohol, the chromic acid is at first set free and is then decomposed, a green solution of the chloride of chromium being generated.

The only native chromate hitherto discovered is the red dichromate of protoxide of lead from Siberia, in the examination of which Vauquelin made the discovery of chromium.

865. *Chromate of Potassa.*—The neutral chromate, from which all the compounds of chromium are directly or indirectly prepared, is made by heating to redness the native oxide of chromium and iron, commonly called *chromate of iron*,* with nitrate of potassa, when chromic acid is generated, and unites with the alkali of the nitre. The object to be held in view is to employ so small a proportion of nitre, that the whole of the alkali may combine with chromic acid, and constitute a neutral chromate, which is easily obtained pure by solution in water and crystalization. For this purpose the chromate of iron is mixed with about a fifth of its weight of nitre, and exposed to a strong heat for a considerable time; and the process is repeated with those portions of the ore which are not attacked in the first operation. It is deposited from its solution in small prismatic anhydrous crystals of a lemon-yellow color, the primary form of which is a right rhombic prism.

Chromate of potassa has a cool, bitter, and disagreeable taste. It is soluble to great extent in boiling water, and in twice its weight of that liquid at 60°; but it is insoluble in alcohol.

866. *Bichromate of Potassa.*—The bichromate of potassa, which is made in large quantity at Glasgow for dyeing, is prepared by acidulating the neutral chromate with sulphuric, or still better, with acetic acid, and allowing the solution to crystalize by spontaneous evaporation. When slowly formed it is deposited in four-sided tabular crystals, the primary form of which is an oblique rhombic prism. They have an exceedingly rich red color, are anhydrous, and consist of one equivalent of the alkali, and two equivalents of chromic acid. They are soluble in about ten times their weight of water at 60°, and the solution reddens litmus paper.

The insoluble salts of chromic acid, such as the chromates of baryta and oxides of zinc, lead, mercury, and silver, are prepared by mixing the soluble salts of those bases with a solution of chromate of potassa. The three former are yellow, the fourth orange-red, and the fifth deep red or purple.

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* This mineral is found abundantly in various parts of the United States.

867. *Chromate of Lead.*—This is the beautiful yellow pigment called *chrome yellow.* It consists of one equivalent of the acid and one equivalent of the protoxide of lead. It is formed by mixing solution of chromate of potassa with acetate or nitrate of lead.

A bibasic or dichromate, composed of one equivalent of chromic acid and two equivalents of protoxide of lead, may be formed by boiling the carbonate of that oxide with excess of chromate of potassa. It is of a beautiful red color, and has been recommended as a pigment.

Chromate of zinc may be used for the same purpose as the chromate of lead.

BORATES.

868. The boracic is a feeble acid, and never neutralizes the alkalies perfectly; and therefore when its salts are digested with any of the more powerful acids, as the sulphuric or nitric, the boracic acid is separated from its base. This does not happen, however, at high temperatures, for boracic acid, owing to its fixed nature, decomposes at a red heat all salts, not excepting sulphates, the acid of which is volatile.

The borates of the alkalies are soluble in water, but most of the other salts of this acid are of sparing solubility. They are not decomposed by heat, and the alkaline and earthy borates resist the action of heat and combustible matter. They are remarkably fusible in the fire, a property obviously owing to the great fusibility of boracic acid itself.

The borates are distinguished by the following character: By digesting any borate in a slight excess of strong sulphuric acid, evaporating to dryness, and boiling the residue in strong alcohol, a solution is formed, which has the property of burning with a green flame.

869. *Biborate of Soda.*—This salt, the only borate of importance, occurs native in some of the lakes of Thibet and Persia, and is extracted from this source by evaporation. It is imported from India in a crude state, under the name of *tincal,* which, after being purified, constitutes the *refined borax* of commerce. It is also prepared to some extent by neutralizing the native boracic acid found in Tuscany with carbonate of soda. When exposed to heat the crystals are first deprived of their water of crystalization, and then fused, forming a vitreous, transparent substance, called *glass of borax.*

The chief use of borax is as a flux, and for the preparation of boracic acid. Biborate of magnesia is a rare natural production, which is known to mineralogists by the name of *boracite.*

CARBONATES.

870. The carbonates are distinguished from other salts by being decomposed with effervescence, owing to the escape of carbonic acid gas, by nearly all the acids; and nearly all of them may be deprived of their acid by heat. Several require an intense white heat to decompose them, but others, as the carbonates of lime and magnesia, are reduced to the caustic state by a full red heat.

All the carbonates except those of potassa, soda, and ammonia, are of sparing solubility in pure water; but all of them are more or less soluble in an excess of carbonic acid, owing doubtless to the formation of supersalts. Thus, carbonate of lime is nearly insoluble in pure water, but water impregnated with carbonic acid dissolves a considerable portion of it, which however is deposited when the excess of acid escapes. Hence the water of many springs impregnated with this gas, deposite the carbonate of lime, &c., which had been held in solution, on coming into the open air, forming the mounds that frequently surround mineral springs.

871. Several of the carbonates occur native, among which may be enumerated the carbonates of soda, baryta, strontia, lime, magnesia, and the protoxides of manganese, iron, copper, and lead; together with some double carbonates, such as dolomite, the double carbonate of lime and magnesia, and barytocalcite, the double carbonate of baryta and lime.

872. The composition of some of the principal carbonates is stated in the following table:

Names.	*Base.*	*Acid.*	*Equiv.*	*Symbols.*
Carbonate of potassa	1 eq. +	1 eq.	69.27	KO,CO_2
Bicarbonate of potassa	1 eq. +	2 eq.	91.39	$KO,2CO_2$
Do. do. in crystals with 1 eq. of water			100.39	
Carbonate of soda	1 eq. +	1 eq.	53.42	NaO,CO_2
Do. do. in crystals with 10 eq. of water			143.42	
Do. do. in crystals with 7 eq. of water			116.42	
Bicarbonate of soda	1 eq. +	2 eq.	75.54	$NaO,2CO_2$
Do. do. in crystals with 1 eq. of water			84.54	
Carbonate of ammonia	1 eq. +	1 eq.	39.27	H_3N,CO_2
——— baryta	1 eq. +	1 eq.	98.82	BaO,CO_2
——— strontia	1 eq. +	1 eq.	73.92	SrO,CO_2
——— lime (marble)	1 eq. +	1 eq.	50.62	CaO,CO_2
——— magnesia	1 eq. +	1 eq.	42.82	MgO,CO_2

873. *Carbonate of Potassa.*—This salt has a taste strongly saline, is slightly caustic, and communicates a green tint to the blue color of the violet. It dissolves in less than an equal weight of water at 60°, deliquesces rapidly on exposure to the air, and crystalizes with much difficulty from its solution. In pure alcohol it is insoluble. It fuses at a full red heat, but undergoes no other change. It is best obtained in a state of

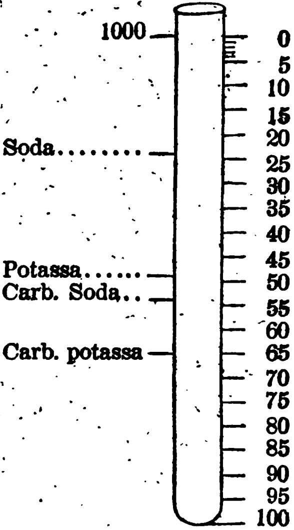
purity by calcining tartrate of potassa in the open air, by which the tartaric acid is decomposed and carbonic acid formed, which combines immediately with the potassa. The mass is then to be digested in pure water and filtered and carefully evaporated.

874. The *potash* of commerce is procured from the ashes of land plants by lixiviating them, and evaporating the solution to dryness. It consists of carbonate of potassa, mixed with variable proportions of other salts, and a minute quantity of vegetable inflammable matter. Calcination at a moderate heat, burns off the coloring particles, and the salt becomes of a spongy texture and beautiful bluish-white tinge, and takes the name of *pearlash.*

Most of the potash of commerce is manufactured in the United States and the Canadas, and in Russia. The American has the preference in the market, as containing less impurities than the European.

875. An instrument called an *alkalimeter*, has been invented by Faraday to determine the quantity of real carbonate of potassa or soda in the impure carbonate, which is often important.

Fig. 84.



Into a glass tube sealed at one end, about 9½ inches long, and ¾ of an inch in diameter, and as cylindrical as possible in its whole length, pour 1000 grains of water, and with a file or diamond mark the place where its surface reaches, and divide the space occupied by the water into 100 equal parts, as is shown in the annexed wood-cut. Opposite to the numbers 23.44, 48.96, 54.63, and 65, draw a line, and at the first write soda, at the second potassa, at the third carbonate of soda, and at the fourth carbonate of potassa. Then prepare a dilute acid, having the specific gravity of 1.127 at 60°, which may be made by mixing one measure of concentrated sulphuric acid with four measures of distilled water. This is the standard acid to be used in all the experiments, being of such strength, that when poured into the tube till it reaches either of the four marks just mentioned, we shall obtain the exact quantity which is necessary for neutralizing 100 grains of the alkali written opposite to it. If, when the acid reaches the words *carb. potassa*, and when, consequently, we have the exact quantity which will neutralize 100 grains of that carbonate, pure water be added until it reaches 0, or the beginning of the scale, each division of this mixture will neutralize one grain of carbonate of potassa. All that is now required, in order to ascertain the quantity of real carbonate in any specimen of pearlash, is to dissolve 100 grains of the sample in warm water, filter to remove all the insoluble parts, and add the dilute acid in successive small quantities, until by the test of litmus paper, the solution is exactly neutralized. Each division of the mixture indicates a grain of pure carbonate.

Carbonate of potassa is used extensively in the manufacture of glass and of soap. For the manufacture of glass the finest pearlash is required.

876. *Bicarbonate of Potassa.*—This salt is made by transmitting a current of carbonic acid gas through a solution of the carbonate; or by evaporating a mixture of the carbonates of ammonia and potassa, the ammonia being dissipated in a pure state. By slow evaporation, the bicarbonate is deposited from the liquid in hydrated prisms with eight sides, terminated with dihedral summits, the primary form of which is a right rhomboidal prism.

It is also prepared in a very economical manner by distillers, from common pearlash, by subjecting it in lumps to the action of the carbonic acid in their fermenting vats, where this gas is of course constantly liberated. In consequence of its having received an additional quantity of gas, it has been called *aerated kali*, or more generally, *sal-æratus*.

Bicarbonate of potassa, though far milder than the carbonate, is alkaline both to the taste and to test paper. It does not deliquesce on exposure to the air. It requires four times its weight of water at 60° for solution, and is much more soluble at 212°; but it parts with some of its acid at that temperature. At a low red heat it is converted into the carbonate. It is much used by bakers.

This salt always contains an equivalent of water, from which it cannot be separated without destroying the salt. It is therefore supposed to be in reality a double salt, composed of carbonate of potassa and carbonate of water. Its composition, therefore, is $KO,CO_2 + HO,CO_2$.

877. *Carbonate of Soda.*—The carbonate of soda of commerce is obtained by lixiviating the ashes of sea-weeds, in the same manner as the carbonate of potassa is obtained from the ashes of land plants. It is the *sal-soda* or *barilla* of commerce; an inferior kind is also called *kelp*.

Much of the carbonate of soda of commerce is manufactured from the sulphate of soda that is formed from common salt, in the process for preparing hydrochloric acid (542). The sulphate of soda is mixed with its own weight of chalk and half its weight of charcoal; and after being reduced to a fine powder, is exposed to full red heat for an hour, by which a black mass is formed called *black-ash*, or *British barilla*, composed of sulphuret of calcium and carbonate of soda, with excess of carbon and other substances. This is then digested in water and filtered, and the solution evaporated to dryness, and again heated to redness with a fourth of its weight of saw-dust, in order to convert all the alkali into carbonate, and expel any sulphur that may remain. By again digesting in water, filtering, and evaporating, the substance called *white-ash* or *soda-ash* is obtained, containing 45 or 50 per cent. of the real carbonate. From this the pure carbonate is procured without difficulty.

This salt crystalizes in octohedrons with a rhombic base, the acute angles of which are generally truncated. The crystals effloresce on exposure to the air, and when heated dissolve in their water of crystalization. By continued heat they are rendered anhydrous, without loss of carbonic acid. They dissolve in about two parts of cold, and in rather less than their weight of boiling water, and the solution has a strong alkaline taste and reaction. The crystals commonly found in commerce contain ten equivalents of water; but when formed at a temperature of about 80°, they retain only seven equivalents.

The purity of different specimens of barilla, or other carbonates of soda, may be ascertained by means of the alkalimeter above described.

878. *Bicarbonate of Soda.*—This salt is made by the same process as bicarbonate of potassa, and is deposited in hydrated crystaline grains by evaporation. Though still alkaline, it is much milder than the carbonate, and far less soluble, requiring about ten times its weight of water at 60° for solution. It is decomposed partially at 212°, and is converted into the carbonate by a red heat.

It is the salt used with tartaric acid in preparing the common effervescing draught.

In consequence of the improved methods of preparing the preceding salt from which this is formed, the price of it has fallen, during the last six or eight years, more than fifty per cent.

Carbonate of Ammonia.—The only method of preparing this compound is by mixing perfectly dry carbonic acid and ammoniacal gases. They combine only in the ratio of one volume of the former to two volumes of the latter, and condense in a white, light powder. It contains carbonic acid and ammonia in equivalent proportions, but the body, in all probability, is not a direct compound of these substances as such.

879. *Sesquicarbonate of Oxide of Ammonium.*—This is the common carbonate of ammonia, or *sal volatile* of the shops, as at first prepared. It is formed by heating a mixture of one part of hydrochlorate of ammonia with one part and a half of carbonate of lime carefully dried. Double decomposition ensues during the process: chloride of calcium remains in the retort, and hydrated sesquicarbonate of ammonia is sublimed. The carbonic acid and ammonia are, indeed, in proper propor

tion in the mixture for forming the real carbonate; but from the heat employed in the sublimation, part of the ammonia is disengaged in a free state.

The salt thus formed consists of 34.3 parts or two equivalents of ammonia, 66.36 parts or three equivalents of carbonic acid, and 18 parts or two equivalents of water. When recently prepared, it is hard, compact, translucent, of a crystaline texture, and pungent, ammoniacal odor; but if exposed to the air it loses weight rapidly from the escape of pure ammonia, and becomes an opaque, brittle mass, which is the bicarbonate.

880. *Carbonate of Baryta* occurs abundantly in the lead mines of the north of England, where it was discovered by Withering, and has hence received the name of *Witherite.*

Carbonate of Strontia occurs native at Strontian, in Argyleshire, and is known by the name of *Strontianite.*

All the salts of baryta are poisonous except those which are absolutely insoluble.

881. *Carbonate of Lime.*—This salt is a very abundant natural production, and occurs under a great variety of forms, such as common limestone, chalk, marble, and Iceland spar.

Quicklime used in masonry is prepared from this mineral as above described (628), by expelling the carbonic acid by heat.

Carbonate of Magnesia also occurs as a natural production, and is called *magnesite* by mineralogists.

882. *Carbonate of Protoxide of Iron.*—Carbonic acid does not form a definite compound with peroxide of iron, but with the protoxide it constitutes a salt which is an abundant natural production, occurring sometimes massive, and at other times crystalized in rhombohedrons or hexagonal prisms. This protocarbonate is contained also in most of the chalybeate mineral waters, being held in solution by free carbonic acid; and it may be formed by mixing an alkaline carbonate with the sulphate of protoxide of iron. When prepared by precipitation, it attracts oxygen rapidly from the atmosphere, and the protoxide of iron, passing into the state of peroxide, parts with carbonic acid. For this reason, the carbonate of iron of the Pharmacopœia is of a red color, and consists chiefly of the peroxide.

883. *Bibasic Carbonate of Protoxide of Copper.*—It occurs as a hydrate in the beautiful green mineral called *malachite;* and the same compound, as a green powder, the *mineral green* of painters, may be obtained, by precipitation from a hot solution of sulphate of protoxide of copper by carbonate of soda or potassa. When obtained from a cold solution, it falls as a bulky hydrate of greenish-blue color, which contains more water than the green precipitate. By careful drying its water may be expelled. When the hydrate is boiled for a long time in water it loses both carbonic acid and combined water, and the color changes to brown. The rust of copper, prepared by exposing metallic copper to air and moisture, is a hydrated dicarbonate.

The blue-colored mineral called *blue copper ore*, appears to be a compound of hydrate and carbonate of the protoxide of copper.

The blue pigment called *verditer*, prepared by decomposing nitrate of oxide of copper with chalk, has a similar composition.

884. *Carbonate of Protoxide of Lead.*—This salt, which is the *white lead* or *ceruse* of painters, occurs native in white prismatic crystals derived

from a right rhombic prism, the specific gravity of which is 6.72. It is prepared as an article of commerce from the subacetate by a current of carbonic acid, by exposing metallic lead in minute division to air and moisture, and by the action on thin sheets of lead of the vapor of vinegar, by which the metal is both oxydized and converted into a carbonate.

The white lead of commerce is not a simple carbonate, but is composed of variable mixtures of different basic carbonates.

There are several double carbonates, but the most important is the double carbonate of lime and magnesia, which occurs native and is called by mineralogists, *bitter spar*, *pearl spar*, and *Dolomite*. *Magnesian limestone* is an impure compact variety.

SECTION III.

ORDER II.—HYDRO-SALTS.

885. In this section are included those salts only, the acid or base of which is a compound containing hydrogen as one of its elements. These are reduced to a small number, as many of the compounds that have formerly been considered *hydrochlorates* of metallic oxides are found to be *chlorides* of the metals themselves. The same remark applies to the hydriodic, hydrocyanic, and other similar acids. The only salts, indeed, which are included in this class, are the compounds of the hydracids with ammonia. Some of the most important of them are constituted as follows:—

Names.	*Base.*	*Acid.*	*Equiv.*	*Symbols.*
Hydrochlorate of ammonia	1 eq. +	1 eq.	53.57	H_3N,HCl
Hydriodate do.	1 eq. +	1 eq.	144.45	H_3N,HI
Hydrobromate do.	1 eq. +	1 eq.	96.55	H_3N,HBr
Hydrosulphate do.	1 eq. +	1 eq.	34.25	H_3N,HS
Fluoborate do.	1 eq. +	1 eq.	84.09	H_3N,BF_3
Fluosilicate do.	1 eq. +	1 eq.	95.70	H_3N,SiF_3

886. *Hydrochlorate of Ammonia.*—This salt, the *sal ammoniac* of commerce, was formerly imported from Egypt, where it is procured by sublimation from the soot of camel's dung; but it is now manufactured in Europe by several processes. The most usual is to decompose sulphate of ammonia by the chloride either of sodium (612) or magnesium, when double decomposition ensues, giving rise in both cases to hydrochlorate of ammonia, and to sulphate of soda, or sulphate of magnesia, according to which salt has been used. The sal ammoniac is afterwards obtained in a pure state by sublimation. In England it is obtained by lixiviating the soot of coal, digesting with sulphuric acid, by which process sulphate of ammonia is formed, and then subliming with common salt.

Hydrochlorate of ammonia has a pungent, saline taste, has a density of 1.45, and is tough and difficult to be pulverized. It is soluble in alcohol and water, requiring for solution three times its weight of water at 60°, and an equal weight at 212° It usually crystalizes from its solution in feathery crystals, but sometimes in cubes or octohedrons. At a temperature below that of ignition it sublimes without fusion or decomposition, and condenses on cool surfaces as an anhydrous salt, which absorbs humidity in a damp atmosphere, but is not deliquescent.

It is said to receive its name, *sal ammoniac*, from the fact that it was first obtained from the vicinity of the temple of Jupiter Ammon.

Hydrochlorate of ammonia is used in medicine, and quite extensively in the arts.

It may be known, like all the salts of ammonia, by yielding the peculiar pungent odor of ammonia when triturated with recently-slaked lime.

887. *Hydrosulphate of Ammonia.*—This salt, also called hydrosulphuret of ammonia, and formerly the *fuming liquor of Boyle*, is prepared by heating a mixture of one part of sulphur, two of sal ammoniac, and two of unslaked lime. It may also be formed by the direct union of its constituent gases, and if they are mixed in a glass globe kept cool by ice, the salt is deposited in crystals. It is much used as a reagent, and for this purpose is usually prepared by saturating a solution of ammonia with hydrosulphuric acid gas.

SECTION IV.

ORDER III.—SULPHUR SALTS.

888. THE compounds described in this section are double sulphurets, just as the oxy-salts in general are double oxides. Their resemblance in composition to salts is perfect.

The sulphurets entering into their composition, it will be recollected, are divided into two classes, called the *sulphur-bases* and the *sulphur-acids* (798). The former or electro-positive elements, are the sulphurets of potassium, sodium, barium, strontium, calcium, magnesium, and hydrosulphate of ammonia, and the latter, or electro-negative elements, are the sulphurets of arsenic, antimony, tungsten, molybdenum, tin, gold, &c., and hydrosulphuric acid, sulphuret of selenium, and bisulphuret of carbon. The sulphur-salts with two metals, are so constituted, that if the sulphur in each were replaced by an equivalent quantity of oxygen, an oxy-salt would result (799).

The sulphur-salts may be divided into families, characterized by containing the same sulphur-acid. For the purpose of indicating that such salts are double sulphurets, as well as to distinguish them readily from other kinds of salts, the generic name of each family is constructed from the sulphur-acid.

Thus the salts which contain persulphuret of arsenic, or hydrosulphuric acid as the sulphur-acid, are termed *arsenio-sulphurets* and *hydro-sulphurets;* and a salt composed of these sulphur-acids with sulphuret of potassium, is termed *arsenio-sulphuret* and *hydro-sulphuret* of sulphuret of potassium. For the sake of brevity the metal of the base may alone be expressed, it being understood that the positive metal in a sulphur-salt enters as a protosulphuret into the compound.

The class of sulphur-salts is somewhat extensive, including several families of hydrosulphurets, carbo-sulphurets, arsenio-sulphurets, &c., but most of them are of little practical importance. A single salt only will be described, the

889. *Hydrosulphuret of Potassium.*—This salt is a compound of hydrosulphuric acid and sulphuret of potassium. It may be obtained in the anhydrous state by introducing anhydrous carbonate of potassa into a tubulated retort, transmitting through it a current of hydrosulphuric acid gas, and heating the salt to low redness. The mass becomes black, fuses, and boils from the escape of carbonic acid gas and aqueous vapor; and after the ebullition has ceased, the gas is continued to be transmitted, until the retort is quite cold. The resulting anhydrous hydrosulphuret of potassium, though black while in fusion, is white when cold, and of a crystaline texture; but if air had not been perfectly excluded, it has a yellow tint, owing to the presence of some bisulphuret of potassium.

The same salt is prepared in the moist way by introducing a solution of pure potassa, free from carbonic acid, into a tubulated retort, expelling atmospheric air by a current of hydrogen gas, and then saturating the solution with hydrosulphuric acid. The solution should be evaporated in the retort to the consistence of syrup, a current of hydrogen gas being transmitted through the apparatus the whole time; and on cooling, the salt crystalizes in large four or six-sided prisms, which are colorless if air was perfectly excluded. The crystals contain water of crystalization, have an acrid, alkaline, and bitter taste, deliquesce in open vessels, and dissolve freely in water and alcohol. On exposure to the air it acquires a yellow color, from the formation of bisulphuret of potassium.

Some of the sulphur-salts occur native as the *copper pyrites* of mineralogists, which is a double sulphuret of iron, and copper, and on the principles we have adopted, may be called ferro-sulphuret of copper.

SECTION V.

ORDER IV.—HALOID SALTS.

890. In this section are included substances composed like the preceding salts of two bi-elementary compounds, one or both of which are analogous in composition to sea-salt. The principal groups consist of double chlorides, double iodides, and double fluorides. In these the haloid bases belong usually to the electro-positive metals, and the haloid-acids to the metals which are electro-negative.

This order includes numerous families, as the hydrargo-chlorides, auro-chlorides, platino-iodides, oxy-chlorides, boro-fluorides, &c. Many of the salts in this class occur native, and several are used extensively in the arts.

HYDRARGO-CHLORIDES.

891. The haloid-acid of this family is bichloride of mercury, which reddens litmus paper, and loses the property when a haloid-base is present, thus bearing a close analogy to ordinary acids.

There are five compounds known to belong to this family, the most important of which is the *dihydrargo-chloride of hydro-chlorate of ammonia*, which has long been known under the name of *salt of alembroth*. It is prepared by mixing its ingredients in the proper atomic proportion, and setting the solution aside to crystalize. Its symbol is $2(H_3N+HCl)+HgCl_2$, from which its combining number may be readily calculated.

PLATINO-CHLORIDE.

892. *Platino-bichloride of Hydrochlorate of Ammonia.*—This salt falls as a lemon-yellow powder when solution of sal ammonia is poured into a strong solution of the bichloride of platinum. It crystalizes in small octohedrons from its aqueous solution by slow evaporation. This salt is always formed in the preparation of metallic platinum from its ores, and when heated to redness, the acid, chlorine, and ammonia are expelled, leaving the metal in a spongy state (784). Its symbol is $(H_3N+HCl)+PtCl_2$.

OXY-CHLORIDES.

893. Chemists are acquainted with a considerable number of compounds in which a metallic oxide is united with a chloride either of the same metal, which is the most frequent, or of some other metal. These compounds are commonly termed *sub-muriates*, on the supposition that they consist of hydrochloric acid combined with two or more equivalents of an oxide.

894. *Oxy-chloride of Copper.*—This compound falls as a green hydrate when potassa is added to a solution of chloride of copper insufficient for its complete decomposition. When its water is expelled it becomes of a liver-brown color. Berzelius states it to consist of one equivalent of the chloride and three equivalents of oxide of copper. It is used as a pigment, under the name of *Brunswick green*, being prepared for that purpose by exposing metallic copper to hydrochloric acid, or a solution of sal ammoniac. The same compound is generated during the corrosion of copper in sea-water.

895. *Oxy-chlorides of Lead.*—A compound of one equivalent of protochloride to two equivalents of protoxide of lead has been found as a colorless mineral. Another oxy-chloride with three equivalents of the protoxide is

prepared by adding pure ammonia to a hot solution of chloride of lead. It falls as a heavy white hydrate; but on expelling its water by heat, it acquires a pale yellow color. A third oxy-chloride, with a still larger proportion of oxide, is used as a pigment, under the name of *mineral* or *patent yellow;* and it is prepared by the action of moist sea-salt on litharge, by which means portions of the protoxide and sea-salt exchange elements, yielding soda and chloride of lead. After washing away the alkali, the mixed oxide and chloride are dried and fused.

There are numerous other haloid salts, which cannot be here introduced.

PART III.

ORGANIC CHEMISTRY.

CHAPTER I.

ON THE GENERAL PRINCIPLES OF THE CONSTITUTION O ORGANIC BODIES.

SECTION I.

GENERAL REMARKS.

896. In the second part of this work, the chemical history of all known elementary substances, and that of many of their compounds, has been given with as much minuteness as was judged consistent with its primary design, so far as their various actions upon each other are concerned, *independent of the principle of life.*

The department of organic chemistry comprehends the history of those compounds which are of animal or vegetable origin, and which are hence called organic substances. These bodies, viewed collectively, form a remarkable contrast with those of the mineral kingdom, the action of affinity in uniting their elements being essentially modified by the principle of life. They in general consist of the same elementary principles, oxygen, hydrogen, carbon, and nitrogen. Some few organic substances also contain phosphorus, sulphur, lime, &c., but the quantity is always exceedingly small. In this respect they differ essentially from inorganic substances.

897. Organic bodies also usually contain a much greater number of simple atoms than inorganic compounds. Thus an atom of albumen contains no less than 883 simple atoms, (or, according to one author, 1765 atoms), and an atom of spermaceti includes 431 simple atoms, numbers to which we find no approximation in any mode of combination of inorganic compounds.

898. The elements of organic bodies are united with each other in definite proportion; and, therefore, the same laws of combination which regulate the composition of mineral substances must likewise influence that of organic compounds. In the latter, however, the modes of combination are generally of a complex kind, and are but imperfectly understood. The same difficulty occurs in inorganic chemistry when the composition is complex. A single molecule of a metallic oxide or

a chloride, as determined by its combining weight, consists of two elements, and usually of two or three atoms only. Thus, in an equivalent of potassa, the chemist has to do with a single equivalent of potassium and of oxygen, between which one kind of combination only is practicable. In an equivalent of sulphuric acid there are four atoms, which admit of three different arrangements; for S and 3O may be united as S+3O, or SO+2O, or SO_2+O.

But in organic compounds a single combining molecule is often made up of so many elementary particles, that one is bewildered by the multiplicity of possible modes of combination. An equivalent of tartaric acid contains 4 equivalents of carbon, 2 equivalents of hydrogen, and 5 equivalents of oxygen, which it is obvious may be arranged in a variety of ways; and other more complex instances might be mentioned.

Organic substances, owing to the energetic affinities with which their elements are endowed, are prone to spontaneous decomposition. This is as we should expect; for the particular order or manner in which the elements are united having been occasioned by the principle of life, when this principle has ceased to act, and the elements come again under the sole influence of their affinities, a change in the order of their arrangement, or, in other words, spontaneous decomposition, must of course take place.

899. Many of the principles or definite compounds which occur among organic bodies, it is very difficult if not impossible to obtain in a separate state; others, because of their crystalizing, or entering into combination with some other substances from which they may be separated, are more readily procured. Still others are volatile, and are formed or driven off at particular temperatures, and thus afford the chemist the means of procuring them in a state of purity.

900. There is great difficulty also in fixing upon a systematic arrangement of organic substances, in consequence of our want of knowledge of their real nature and relations. The first very natural division is into the two classes of vegetable and animal, according as they are produced in the vegetable or animal kingdom; but even this simple arrangement is not without objection. It is, however, adopted in this work, though some substances will require to be noticed in both divisions, and others, properly of animal origin, will most naturally be described in connection with vegetable bodies. It is hoped, however, that no inconvenience will be found to result from it.

901. Formerly it was considered characteristic of organic substances that they cannot be formed artificially, by direct union of their elements; but a few exceptions are now known, as in the case of urea and one or two other compounds.

902. Many organic bodies are distinctly acid, not only to the taste, but possess other properties of acids; they redden the vegetable blue and unite

with and neutralize the most powerful alkalies. They are found both among vegetable and animal products.

Other organic principles as evidently belong to the class of bases; they are capable of forming definite compounds with acids, both organic and inorganic, and neutralizing them more or less perfectly. They are found chiefly if not wholly among vegetable bodies.

A third group of organic compounds may be denominated "neutral principles," as being neither acid nor alkaline. A fourth group is called "intermediate principles." Some of the bodies included in it are capable of combining with acids and others with alkalies, but their properties are not sufficiently marked to entitle them to a place with either of these classes. In this work these two families are described together.

Besides the above, the various oleaginous, resinous, and bituminous substances, possess sufficient points of resemblance to entitle them to description in a single section. The compounds of the radical cyanogen are so numerous and important that they are also described together, as in other works.

903. It has already been remarked (296) that the systematic nomenclature does not apply to the names of the organic acids, which are generally derived from the substances from which they are obtained. Thus malic acid is so called because it is obtained from the apple, *malum*; so citric acid is obtained from the lemon, *citron*, and benzoic acid from gum benzoin, &c. The same might be said of the vegetable alkalies and other principles. Thus, cinchonia is obtained from the bark of the *cinchonia condaminea*, veratria from the *veratrum album*, salicin from a species of *salix*, &c.

904. In the names of the salts formed by the organic acids and alkalies, the same principle is followed as is observed in inorganic chemistry. Thus we have sulphate of morphia, acetate of quinia, bitartrate of potassa, &c. In the names of most of the compound radicals, hereafter to be described, no regular system has been observed.

The laws of combination as heretofore explained (328) apply to the various products of organic bodies, and symbols are also used in organic precisely as in mineral chemistry.

905. All organic compounds are decomposed by being heated to redness, whether in the open air, in contact with other substances, or in close vessels; and complicated changes often take place. This is called the destructive distillation of these substances.

906. Organic bodies are also generally decomposed by the action of the stronger mineral acids, as the sulphuric and nitric, and new and entirely different compounds formed.

SECTION II.

COMPOUND RADICALS.

907. The term "compound radical" is used to denote individuals of a class of compound bodies which possess the property of uniting with elementary substances, and forming with them combinations that are analogous in their properties to combinations of two simple bodies; combinations therefore in which

the elementary body may be removed, and its place occupied by equivalent quantities of other simple bodies. They are capable also of uniting with each other as well as with simple substances; and forming important and stable compounds. With oxygen and sulphur they form acids and bases, precisely as simple bodies (795); and with hydrogen many of them form *hydracids.*

908. The following table contains a few of the most important of these compounds, with their equivalents, and exhibits their composition, by means of their symbols. It should be remarked however that all of them have not yet been obtained in a separate state. But though not separated entirely from other matter, it is believed sufficient evidence has been obtained of their existence.

TABLE OF COMPOUND RADICALS

Names.	*Equiv.*	*Symbols.*
Ethule*	29.48	C_4H_5 or Ae
Acetule*	27.48	C_4H_3 — Ac
Cyanogen	26.39	C_2N — Cy
Amide*	16.15	NH_2 — Ad
Carbonic oxide	14.12	CO
Melam	238.09	$C_{12}N_{11}H_9$
Melamine	121.62	$C_6N_6H_6$
Ammeline	128.47	$C_6N_5H_5O_2$
Ammelide	257.79	$C_{12}N_9H_9O_6$
Uramile	144.41	$C_8N_3H_5O_6$
Murexide	197.19	$C_{12}N_5H_6O_8$
Benzule*	106.68	$C_{14}H_5O_2$ or Bz
Aldehyde	44.48	$C_4H_4O_2$

909. The manner of preparing several of those which have been obtained free from other substances, will be described hereafter. The evidence on which the real existence of those which have not been obtained in a separate state rests, may be seen by referring to a single example. Benzule, composed of $C_{14}H_5O_2$ has never been insulated, but if we treat oil of bitter almonds, $C_{14}H_6O_2$, by chlorine, we obtain a compound $C_{14}H_5O_2Cl$, which gives with iodide or sulphuret of potassium, bodies whose formulæ are respectively $C_{14}H_5O_2I$, and $C_{14}H_5O_2S$. Again, acted on by oxygen, it gives crystalized benzoic acid, $C_{14}H_5O_4$, or rather $C_{14}H_5O_3 + HO$. Now it is evident that throughout this whole series the element, $C_{14}H_5O_2$, has remained unaltered. In the oil it was combined with hydrogen, in benzoic acid with oxygen, and in the other compounds mentioned, with iodine and sulphur respectively; and in denominating it the root or radical of all these compounds, we but give expression to a determined fact. This radical, as we have already remarked, is called Benzule—symbol Bz—and its compounds named above may be written BzH, BzCl, BzI, and BzO+HO. They are evidently the hyduret, chloride, iodide, and oxide of benzule, the latter containing an atom of water of crystalization.

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* These compounds have never yet been obtained in a separate state.

910. If from a compound radical one or more of its constituents be removed, a new radical is sometimes formed in a free or combined state, and sometimes a new compound of another radical. Thus, if we digest oil of bitter almonds, $C_{14}H_6O_2$, with ammonia, all the oxygen is removed, and we obtain a compound of nitrogen with the base, $C_{14}H_5$, which is evidently the radical of benzule, and which may also be combined with other substances besides oxygen, with which it forms benzule. So when the bisulphuret of cyanogen is exposed to a temperature of 266°, it is decomposed into bisulphuret of carbon, sulphur, and mellone:—4 atoms of bisulphuret of cyanogen, $4NC_2S_2 = N_4C_8S_8$, are resolved into C_2S_4, S_4, and N_4C_6. That is, the 4 atoms of bisulphuret of cyanogen are changed into 2 atoms of bisulphuret of carbon, 4 atoms of sulphur, and 1 atom of mellone;—the bisulphuret of carbon being a new compound of a simple radical, carbon, and mellone being a new radical.

Theory of Types.—Bodies are said to be of the same *mechanical type* when they contain the same number of atoms, and of the same *chemical type* when their various properties are similar. Thus alcohol ($C_4H_6O_2$) contains 12 chemical atoms; and when it is converted into acetic acid ($C_4H_4O_4$) no change in this respect takes place, but simply 2 atoms of hydrogen give place to 2 atoms of oxygen. But the properties of acetic acid are entirely different from those of alcohol; these substances are therefore of the same mechanical, but not of the same chemical type. When acetic acid is treated with chlorine, it loses 3 equivalents of hydrogen and gains 3 eq. of chlorine ($C_4H_4O_4 - H_3 + Cl_3 = C_4Cl_3HO_4$), forming chloroacetic acid, which has the same mechanical type, that is, the same number of molecules or atoms as alcohol and acetic acid. And in thus giving up 3 eq. of hydrogen and acquiring as many of chlorine, acetic acid scarcely undergoes any change of properties, and hence is said to retain the same chemical type. So when ether (C_4H_5O) is treated with chlorine, the hydrogen is replaced by the same number of atoms of chlorine, and the properties of the new compound are essentially the same as those of the old; both the mechanical and chemical type therefore remain unchanged.

911. This theory of types is found of great service in tracing the changes that take place among organic substances, as bodies of the same mechanical type containing radicals of the same type, when subjected to the action of strong affinities, by which their constitution is broken up, generally give rise to products which are formed upon the same plan, however they may differ in composition.

912. So also when bodies of the same chemical, though of different mechanical types, are submitted to the action of affinities of equal power, th new products formed have generally the same relations to each other th original bodies had, and the radicals are either unchanged or are change in a similar degree.

CHAPTER II.

VEGETABLE CHEMISTRY.

SECTION I.

GENERAL REMARKS.

913. **Nearly** all vegetable substances are composed exclusively of the three elementary principles, oxygen, hydrogen, and carbon; but some of them also contain nitrogen or sulphur. In examining vegetable substances it is necessary to distinguish between *proximate* and *ultimate principles*. *Proximate principles* are such as are obtained immediately from the plant, as sugar, starch, and gum; but the *ultimate principles* are the elements mentioned above, which are obtained only by the entire destruction of the compound. The proximate principles are sometimes distributed over the whole plant, but at others they are contained only in particular parts, as in the fruit, the leaves, the flower, the bark, the sap, or the root.

914. The separation of the proximate principles of vegetables constitutes their *proximate analysis*, and the reduction of proximate principles into their simplest parts is called their *ultimate analysis*. When the ultimate analysis is made by heating to redness in close vessels, it is called the *destructive distillation*.

SECTION II.

VEGETABLE ACIDS.

915. **Vegetable acids** are a class of bodies possessing the ordinary properties of acids (796), which are found ready formed in plants, either free or in a state of combination. These acids are generally more permanent than most other vegetable substances, but are all decomposed by a red heat or boiling nitric acid.

916. Many of the vegetable acids are polybasic (810), that is, a single equivalent of acid is capable of combining with one, two, or three equivalents of base. The salts of the bibasic acids may contain 2 equivalents of a fixed base, or one equivalent may be a fixed base while the other is water, as described under phosphoric acid (510). So also in the salts of the tribasic acids, one or two of the equivalents may be of water, the rest belonging to a fixed base (514). *Acid salts*, either bibasic or tribasic, are such as contain water; an equivalent of those that are bibasic can of course contain only one equivalent of water,

while an equivalent of those that are tribasic may have two equivalents of water.

917. Several of the acids when exposed to a high temperature are decomposed, and new acids formed called *pyracids*. Thus, tartaric acid, when so treated, yields *pyrotartaric* acid, and gallic, *pyrogallic*, &c. The nature of the change produced will of course depend in a great measure upon the degree of heat which is used. Sometimes carbon and oxygen are given off in the form of carbonic acid, and at others oxygen and hydrogen are expelled united as water. Sometimes both of these substances are given off at the same time.

918. The vegetable acids are very numerous, and but few of them can be described in this work. They may be divided into the four classes of volatile, fixed, oily, and compound acids. The spaces left in the table will indicate these divisions.

Names.	*Equiv.*	*Symbols.*
Oxalic acid,	36.24	C_2O_3
Acetic "	51.48	$C_4H_3O_3$
Succinic "	50.48	$C_4H_2O_3$
Camphoric "	92.2	$C_{10}H_7O^3$
Benzoic "	114.68	$C_{14}H_5O_3$
Cinnamic "	141.16	$C_{18}H_7O_3$
Malic "	116.96	$C_8H_4O^8$
Citric "	166.44	$C_{12}H_5O_{11}$
Tartaric "	132.96	$C_8H_4O_{10}$
Meconic "	174.68	$C_{14}HO_{11}$
Gallic "	67.84	C_7HO_3
Amygdalic "	462.80	$C_{40}H_{26}O_{24}$
Tannic "	187.16	$C_{18}H_5O_9$
Ulmic "	352.80	$C_{40}H_{12}O_{12}$
Stearic "	522.16	$C_{68}H_{66}O_5$
Oleic "	340.28	$C_{44}H_{39}O_4$
Margaric "	275.08	$C_{34}H_{33}O_3$
Althionic "	126.68	$2(SO_3) + C_4H_5O + HO$
Oxalovinic "	118.96	$2(C_2O_3) + C_4H_5O + HO$
Tartravinic "	179.44	$2(C_4H_2O_5) + C_4H_5O + HO$

919. The compound acids, it will be observed, are composed of a vegetable principle united with a mineral or strong vegetable acid. There are various other compound acids besides the above.

OXALIC ACID.

920. This acid was first discovered by Scheele. It is said to occur as a mineral production in combination with protoxide of iron in *humboldtine*.

It exists ready formed in several plants, especially in the *rumex acetosa* or common sorrel, and in the *oxalis acetosella* or wood sorrel; but it almost always occurs in combination either with lime or potassa. These plants contain binoxalate of potassa; and the oxalate of lime has been found in large quantity in several species of lichen.

921. Oxalic acid is easily made artificially by digesting sugar or potatoe starch in five or six times its weight of nitric acid, and expelling the excess of that acid by distillation, until a fluid of the consistence of syrup remains in the retort. The residue in cooling yields crystals of oxalic acid, the weight of which amounts to nearly half the quantity of the sugar or starch employed. They should be purified by repeated solution in pure water, and re-crystalization.

The production of oxalic acid from organic matter by this method is a consequence of the oxydation of the elements of the latter by the oxygen of the nitric acid.

Many organic substances besides sugar, such as gum, most of the vegetable acids, wool, hair, and silk, are converted into oxalic by the action of nitric acid;—a circumstance which is explicable on the fact that oxalic acid contains more oxygen than any other principle, whether of animal or vegetable origin. It is also generated by heating organic substances with potassa.

922. Oxalic acid crystalizes in slender, flattened four and six-sided prisms, terminated by two-sided summits; but their primary form is an oblique rhombic prism. It has an exceedingly sour taste, reddens litmus paper strongly, and forms neutral salts with alkalies. The crystals, which consist of 1 equivalent of real acid and 3 of water, undergo no change in ordinary states of the air; but effloresce slightly in a very dry and warm atmosphere. It possesses considerable volatility, and may be slowly sublimed.

This acid taken internally is a rapid and fatal poison; and frequent accidents have occurred from its being sold and taken by mistake for Epsom salt, with the appearance of which its crystals have some resemblance. These substances may be easily distinguished, however, by the strong acidity of oxalic acid, which may be tasted without danger, while sulphate of magnesia is quite neutral, and has a bitter saline taste.

When the acid has been accidentally swallowed, copious draughts of lime-water, or powdered chalk and water, should be administered, and vomiting excited as soon as possible.

923. Oxalic acid is easily distinguished from all other acids by the form of its crystals, and by its solution giving with lime-water a white precipitate, which is insoluble in an excess of the acid. When the acid is contained in mixed fluids, it may be conveniently precipitated by nitrate of oxide of lead, care being taken beforehand to neutralize the solution with a little carbonate of soda. The precipitated oxalate of oxide of lead, after being well washed, and while yet moist, is suspended in

water, and decomposed by a current of hydrosulphuric acid: the clear liquid is poured off or filtered from the sulphuret of lead, and concentrated by evaporations that crystals may form. These may be purified by solution in pure water and second crystalization.

As an equivalent of oxalic acid contains 2 equivalents of carbon and 3 of oxygen, it may be regarded either as a direct compound of carbon and oxygen, indicated by the formula C_2O_3, or as a compound of carbonic oxide and carbonic acid, denoted by CO,CO_2. It is converted into these substances by the action of heated sulphuric acid.

Oxalic acid, or any oxalate, if soluble, may always be detected by adding to the solution a neutral salt of lime or oxide of lead, when a white oxalate of the base used will be thrown down.

924. *Oxalates of Potassa.*—Oxalic acid forms with potassa three compounds. The first is the neutral oxalate, which is formed by neutralizing carbonate of potassa with oxalic acid. It crystalizes in oblique quadrangular prisms, which have a cooling, bitter taste. This salt is much employed as a reagent for detecting lime. The *binoxalate* is contained in sorrel, and may be procured from that plant by solution and crystalization. It crystalizes readily in small rhomboids, which are less soluble in water than the neutral oxalate. It is often sold under the name of *essential salt of lemons* for removing iron mould, stains of ink, &c., from linen,—an effect which it produces by half of its acid uniting with the peroxide of iron and forming a soluble oxalate. The *quadroxalate* is the least soluble of these salts, and is formed by digesting the binoxalate in nitric acid, by which it is deprived of half its base.

925. *Oxalate of Ammonia.*—This salt, prepared by neutralizing ammonia with oxalic acid, is much used as a reagent. It is very soluble in hot water, and is deposited in acicular crystals when a saturated hot solution is allowed to cool. It is much used as a test for lime, and also to separate lime from magnesia.

926. *Oxalate of Lime.*—This salt, like all the insoluble oxalates, is easily prepared by way of double decomposition. It is a white finely-divided powder, which is remarkable for its extreme insolubility in pure water. On this account a soluble oxalate is an exceedingly delicate test for lime. It is soluble, however, in hydrochloric and nitric acids. It may be exposed to a temperature of 560° without decomposition, and is then quite anhydrous. No binoxalate of lime is known.

This salt is interesting in a pathological point of view, because it is a frequent ingredient of urinary concretions, being the basis of what is called the *mulberry calculus.* It is also found in several species of lichen.

927. *Chloro-carbonic Acid.*—This substance has been called *phosgene gas.* It is formed by exposing equal measures of dry chlorine and carbonic oxide to sunshine, when combination ensues, and they contract to half their volume.

It is a colorless gas, and has a strong disagreeable odor. It may be viewed as carbonic acid, in which one-half of the oxygen has been replaced by chlorine. $CO_2—O+Cl=CO,Cl$.

ACETIC ACID.

928. Acetic acid exists ready formed in the sap of many plants, either free or combined with lime or potassa; it is gene

rated during the destructive distillation of vegetable matter, and is an abundant product of the acetic fermentation.

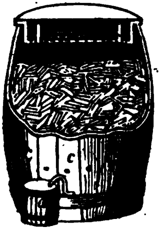
This acid forms the acidifying principle of common vinegar, of which it constitutes about one-twentieth part. Vinegar contains also considerable saccharine and mucilaginous matter.

Vinegar, as the name derived from the French, *vin aigre*, implies, is formed from wine in many countries, but is often made also by subjecting malt liquors or cider to the free access of atmospheric air.

All liquids indeed which are capable of the vinous fermentation may be made to produce this acid; the sugar or starch which they contain is first converted into alcohol, and afterwards by oxydation into acetic acid.

It is now well ascertained that the change from alcohol to acetic acid consists simply in the removal of 2 equivalents of the hydrogen of the alcohol, and addition of 2 eq. of oxygen; these changes not being simultaneous, but successive, aldehyde being the intermediate product. Thus alcohol, $C_4H_6O_2$, by losing 2 eq. of hydrogen, becomes aldehyde, $C_4H_4O_2$; and this, by absorbing 2 eq. of oxygen, forms hydrated acetic acid, $C_4H_4O_4 = C_4H_3O_3 + HO$.

Fig. 85.



The access of atmospheric air is absolutely essential to the formation of vinegar by the ordinary process, as is well known; and its production is much facilitated by a method invented in Germany. A cask, as seen in figure 85, is filled with wood shavings, and closed at top by a pan *b*, the bottom of which is perforated with many small holes, through which small threads are passed to conduct the liquid downward. The shavings being first well soaked in vinegar, are placed lightly in the cask, and below them are several small holes *cc* about half an inch in diameter, to admit the free accession of air. If now proof spirit diluted with four times its weight of water, and having mixed with it a very little honey or yeast, is poured into the pan above, it gradually trickles down upon the shavings, where a large surface being exposed to the atmosphere, rapid absorption of oxygen takes place, the temperature is raised, and acetic acid is rapidly formed. As the liquid passes down it is collected in the vessel *a*; and when passed through three or four times, which requires but about 36 hours, it is converted into excellent vinegar.

The acetic acid now generally employed for chemical purposes or in the arts, is prepared by the distillation of wood, and is sold under the name of *pyroligneous acid.*

929. Concentrated acetic acid is best obtained by decomposing the acetates either by sulphuric acid, or in some instances by heat. A convenient process is to distil acetate of potassa with half its weight of concentrated sulphuric acid, the recipient being kept cool by the application of ice. The acid is at first contaminated with sulphurous acid; but by mixing it with a little peroxide of manganese, and redistilling, it is rendered quite pure. A strong acid may likewise be procured

from acetate of oxide of copper by the sole action of heat. The acid when first collected has a greenish tint, owing to the presence of copper, from which it is freed by a second distillation. Pyro-acetic ether is formed towards the close of the process.

930. Strong acetic acid is exceedingly pungent, and even raises a blister when kept for some time in contact with the skin. It has a very sour taste, and an agreeable, refreshing odor. Its acidity is well marked, as it reddens litmus paper powerfully, and forms neutral salts with the alkalies. It is exceedingly volatile, rising rapidly in vapor at a moderate temperature without undergoing any change. Its vapor is inflammable and burns with a white light. In its most concentrated form it is a definite compound of one equivalent of water, and one equivalent of acid; and in this state it crystalizes when exposed to a low temperature, retaining its solidity until the thermometer rises to 50°. It is decomposed by being passed through red-hot tubes, but owing to its volatility, a large quantity of it escapes decomposition.

Hydrated acetic acid, when free from excess of water, crystalizes at about 50° in large white plates, and is hence called *glacial acetic* acid. In the liquid state it is capable of dissolving camphor, and the essential oils, and various resins. Saturated with camphor or some oil, it constitutes *aromatic vinegar*, and is used as a stimulant against fainting.

The only correct mode of estimating the strength of acetic acid is by its neutralizing power. Its specific gravity is no criterion.

931. *Acetates of Protoxide of Lead.*—The *neutral acetate*, long known by the name of *sugar of lead*, is made by dissolving either the carbonate or litharge in distilled vinegar. The solution has a sweet, succeeded by an astringent taste, does not redden litmus paper, and deposites shining acicular crystals by evaporation. When more regularly crystalized, it occurs in six-sided prismatic crystals, cleaveable parallel to the lateral and terminal planes of a right rhombic prism, which may be regarded as its primary form. The crystals effloresce slowly by exposure to the air, and require about four times their weight of water at 60° for solution.

This salt is partially decomposed, with formation of carbonate of oxide of lead, by water which contains carbonic acid, or by exposure to the air; but a slight addition of acetic acid renders the solution quite clear. It is much used in the arts, in medical and surgical practice as a sedative and astringent, and in chemistry as a reagent.

It is poisonous if taken internally.

Besides the neutral acetate there is a *sesquibasic* and a *tribasic acetate*, neither of which, however, possesses any special interest. The tribasic acetate of lead, the *extractum saturni* of the Pharmacopiæ, is the base of Goulard's extract. A *sexbasic acetate*, it is said, has also been formed.

932. *Acetate of alumina* and *acetate of baryta* are used as mordants by dyers and calico-printers.

Acetates of Copper.—The *neutral* acetate of copper may be formed either by dissolving protoxide of copper or common verdigris in acetic acid, or by decomposing the sulphate by an equivalent quantity of acetate of oxide of lead. On evaporation it readily crystalizes in oblique rhombic prisms of a dark green color, which contain a single equivalent of water. If, however, the temperature of the solution is below 46°, the form of the crystals is varied and they contain 5 equivalents of water, and are of a blue color.

The *bibasic acetate* of copper is the well-known *verdigris* used by painters. It is prepared in large quantity in the south of France, by covering copper with the refuse of the grape after the juice has been extracted for making wine: the saccharine matter contained in the husks furnishes acetic acid by fermentation, and in four or six weeks the plates acquire a coating of the acetate. A purer and better article is prepared by covering copper plates with cloth soaked in pyroligneous acid.

The *sesquibasic* and *tribasic acetates* of copper possess no peculiar interest.

SUCCINIC ACID.

933. This acid is procured by heating powdered amber in a retort by a regulated temperature, when the succinic acid, which exists ready formed in amber, passes over and condenses in the receiver. As first obtained it has a yellow color and peculiar odor, owing to the presence of some empyreumatic oil; but it is rendered quite pure and white by being dissolved in nitric acid, and then evaporated to dryness. The oil is decomposed, and the succinic acid is left unchanged.

Succinic acid has a sour taste, and reddens litmus paper. It is soluble both in water and alcohol, and crystalizes by evaporation in anhydrous prisms. When briskly heated it fuses, undergoes decomposition, and in part sublimes, emitting a peculiar and very characteristic odor.

934. *Succinate of Ammonia* is used in analysis to separate iron from manganese.

CAMPHORIC ACID.

This compound has not hitherto been found in any plant, and is procured only by digesting camphor for a considerable time in a large excess of nitric acid. As the solution cools, the camphoric acid separates out in crystals. It is sparingly soluble in water, fuses at 145°, and sublimes at a temperature by no means elevated. Its taste is rather bitter, and when quite pure has probably no odor. It reddens litmus paper, and combines with alkaline bases, forming salts which are called camphorates: those with the alkalies are very soluble and even deliquescent, but with oxide of lead it forms an insoluble compound.

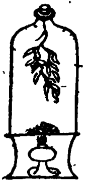
BENZOIC ACID.

935. Benzoic acid exists in gum benzoin, in storax, in the balsams of Peru and Tolu, and in several other vegetable substances.

This acid is commonly extracted from gum benzoin. The usual process consists in boiling finely powdered gum benzoin in a large quantity of water along with lime or carbonate of potassa, by which means a benzoate is formed. To the solution, after being filtered and concentrated by evaporation, hydrochloric acid is added, which unites with the base, and throws down the benzoic acid. It is then dried by a gentle heat, and purified by sublimation.

936. Benzoic acid has a sweet and aromatic rather than a sour taste; but it reddens litmus paper, and neutralizes alkalies. It fuses readily by heat, and at a temperature a little above its point of fusion it is converted into vapor, emitting a peculiar, fragrant, and highly characteristic odor, and condensing on cool surfaces without change. When strongly heated it takes fire, and burns with a clear, yellow flame. It undergoes no change by exposure to the air, and is not decomposed by the action even of nitric acid. It requires about 24 parts of boiling water for solution, and nearly the whole of it is deposited on cooling in the form of minute acicular crystals of a silky lustre. It is very soluble in alcohol, especially by the aid of heat.

Fig. 86.



The sublimation of this acid may be beautifully shown by putting a small quantity of it upon a plate of metal on a stand and placing over it a glass receiver, having suspended in it a small twig of mint or other substance, as shown in figure 86 (from Webster's Chemistry), and applying the heat of a lamp beneath it. In a short time the leaves will be covered with delicate crystals of the acid.

937. This acid is considered an oxide of the compound radical benzule ($C_{14}H_5O_2$), which has already been mentioned. Oil of bitter almonds, $C_{14}H_6O_2$, is a hyduret of this radical, from which the chloride (909), iodide, sulphuret, cyanide, and numerous other compounds of benzule, may be prepared. But they are not of sufficient importance to be here described.

CINNAMIC ACID.

938. This acid ($C_{18}H_7O_3$), is formed when oil of cinnamon is long exposed to the action of the atmosphere, and by other means. By the first method it forms in long translucent prisms, which are slightly soluble in cold or warm water. It is an oxide of the compound radical cinnamule ($C_{18}H_7O_2$).

MALIC ACID.

939. This is a bibasic acid. It is contained in most of the acidulous fruits, being frequently associated with tartaric and citric acids. Grapes, currants, gooseberries, and oranges contain it. Vauquelin found it in the tamarind, mixed with tartaric and citric acids, and in the house-leek (*sempervivum tectorum*) combined with lime. It is contained in considerable quantity in apples, a circumstance to which it owes its name. It is almost the sole acidifying principle of the berries of the mountain ash or service tree (*sorbus aucuparia*).

Malic acid possesses strong acidity, and a pleasant flavor when diluted. It crystalizes with difficulty, attracts moisture from the air, and is very soluble in water and alcohol. Its aqueous solution is decomposed by keeping, and it is converted into the oxalic by digestion in strong nitric acid.

Malic acid forms with bases numerous salts, which, however, are of little importance.

CITRIC ACID.

940. This acid is contained in many of the acidulous fruits, but exists in large quantity in the juice of the lime and lemon, from which it is procured by the following process: To any quantity of lime or lemon juice, finely powdered chalk is added as long as effervescence ensues; and the insoluble citrate of lime, after being well washed with water, is decomposed by digestion in dilute sulphuric acid. The insoluble sulphate of lime is separated by a filter, and the citric acid obtained in crystals by evaporation. They are rendered quite pure by being dissolved in water and recrystalized.

Citric acid crystalizes in cooling from a hot saturated solution in crystals which consist of 1 eq. of the anhydrous acid, and 3, 4, or 5 eq. of water, according to the temperature at which they are formed.

941. Citric acid has a strong sour taste, with an agreeable flavor when diluted, reddens litmus paper, and neutralizes alkalies. In a dry state it may be preserved for any length of time, but the aqueous solution is gradually decomposed by keeping. The crystals are soluble in an equal weight of cold and in half their weight of boiling water, and are also dissolved by alcohol. It is converted into the oxalic by digestion in nitric acid.

Citric acid is characterized by its flavor, by the form of its crystals, and by forming an insoluble salt with lime, and a deliquescent soluble one with potassa. It does not render lime-water turbid unless the latter is in excess, and fully saturated with lime in the cold.

This acid is used in calico-printing, and for medicinal and domestic purposes, instead of lemon juice.

Citric acid being tribasic forms numerous acid and basic salts, according as they contain more or less of combined water (514), but they are not described in this work, as none of them possess any special interest.

TARTARIC ACID.

942. Tartaric acid is bibasic. When crystalized it always contains 2 eq. of water united with 1 eq. of the acid. It exists in the juice of several acidulous fruits, sometimes free, but generally in combination with lime or potassa.

The tartaric acid of commerce is obtained from the juice of the grape, in which it exists in great abundance, combined with potassa. When the juice is pressed from the grape, the salt is held in solution, but being insoluble in spirituous liquor, as the fermentation progresses, it is gradually deposited in irregular crystalized layers on the inside of the casks in which the wine is made. This salt, containing 1 eq. of fixed base and 1 eq. of water, is always acid; and by neutralizing with lime and decomposing the tartrate of lime by sulphuric acid, the pure tartaric acid is obtained, which is easily crystalized by evaporation.

943. Tartaric acid has a sour taste, which is very agreeable when diluted with water. It requires five or six times its weight of water at 60° for solution, but is much more soluble in boiling water. The aqueous solution is gradually decomposed by keeping, and a similar change is experienced, under the same circumstances, by most of the tartrates. The crystals may be exposed to the air without change. They are converted into the oxalic by digestion in nitric acid.

Tartaric acid cannot be deprived of its water of crystalization, except by uniting with an alkaline base: on attempting to expel it by heat, the acid fuses and is decomposed, yielding, if air is excluded, the usual products of destructive distillation, together with *pyrotartaric* or *tartralic acid* (917). A large residue of charcoal is obtained.

944. Tartaric acid is distinguished from other acids by forming a white precipitate, acid tartrate of potassa, when mixed with any of the salts of that alkali. This acid, therefore, separates potassa from other acids. It occasions with lime-water a white precipitate, which is very soluble in an excess of the acid.

945. *Tartrates of Potassa.*—There are two tartrates of potassa, the acid tartrate and the neutral tartrate. The former is composed of 1 eq. of the acid united with 1 eq. of potassa and 1 eq. of water, and is distinctly acid. It is the *cream of tartat* of commerce, and in books is often described as a bitartrate of potassa.

Cream of tartar is very sparingly soluble in water, requiring 60 parts of cold and 14 of boiling water for solution, and is deposited from the latter on cooling in small crystaline grains. Its crystals are commonly irregular six-sided prisms, and its primary form is either a right rectangular, or a right rhombic prism. Its water of crystalization cannot be expelled without decomposing the salt itself.

When this salt is exposed to heat, it is decomposed with the formation of carbonate potassa, which may be obtained very pure by filtration. Hence its name, *salt of tartar.*

The neutral tartrate of potassa, called also *soluble tartar*, is formed by adding cream of tartar to a hot solution of carbonate of potassa. It is neutral in its reaction.

946. *Tartrate of Potassa and Soda.*—This double salt, which has been long employed in medicine under the name of *Siegnette* or *Rochelle Salt*, is prepared by neutralizing acid tartrate of potassa with carbonate of soda. By evaporation it yields prismatic crystals, the sides of which often amount to ten or twelve in number; but the primary form, as obtained by cleavage, is a right rhombic prism.

It may be formed extemporaneously by dissolving cream of tartar in water, and pouring into it solution of bicarbonate of soda, and drinking during the effervescence.

947. *Tartrate of Oxide of Antimony and Potassa.*—This compound, long celebrated as a medicinal preparation under the name of *tartar emetic*, is made by boiling sesquioxide of antimony with a solution of acid tartrate of potassa. The oxide of antimony evidently replaces the eq. of water in the cream of tartar.

Tartar emetic yields crystals, which are transparent when first formed, but become white and opaque by exposure to the air. Its primary form has been correctly described as an octohedron with a rhombic base, but the edges of the base are frequently replaced by planes which communicate a prismatic form, and its summits are generally formed with an edge instead of a solid angle, which edge is frequently truncated, presenting a narrow rectangular surface. Its aqueous solution, like that of all the tartrates, undergoes spontaneous decomposition by keeping; and, therefore, if kept in the liquid form, alcohol should be added in order to preserve it.

Tartar emetic is decomposed by many reagents. Thus alkaline substances, from their superior attraction for tartaric acid, separate the oxide of antimony.

This substance is used in medicine as an emetic, but taken in large doses it is highly poisonous.

MECONIC ACID.

948. This acid is found only in opium. Its name is derived from the Greek, *μηχων*, *poppy*. from which, as is well known, opium is obtained. In the poppy it is probably in combination with morphia, and perhaps other bases, as lime and potassa. The process for procuring it in a pure state, it is not necessary here to transcribe.

It is a tribasic acid, and forms three classes of salts, according as they contain 1, 2, or 3 eq. of fixed base, as in other instances of tribasic acids (514). Meconic acid and solutions of its salts are distinguished by striking a blood-red color by the persalts of iron. None of the meconates are of importance.

GALLIC ACID.

949. Gallic acid is found ready formed in the seeds of the mango; but it is usually prepared by exposing paste made of powdered gall-nuts (an excrescence which grows upon several species of the oak,) and water to the action of the air for a considerable time. Water is added to supply the loss by evapo-

ration, and finally the resulting mass is boiled, and the gallic acid crystalizes on cooling. It may also be formed by digesting powdered gall-nuts in ether, by which an ethereal solution of the acid is procured.

Pure gallic acid crystalizes in oblique rhomboidal prisms of a yellowish color, which are soluble in water and possess a peculiar astringent taste. With the persalts of iron this acid strikes a deep blue-black, by which it is distinguished.

TANNIC ACID.—(TANNIN.)

950. This substance exists in an impure state in gall-nuts; in the bark of most trees; in some inspissated juices, such as kino and catechu; in the leaves of the tea-plant, sumach, and whortleberry, and in astringent plants generally, being the chief cause of the astringency of vegetable matter. It is frequently associated with gallic acid, as in gall-nuts, in most kinds of bark, and in tea.

It may be obtained from powdered gall-nuts by digesting it in ether, which dissolves it. The solution is heavier than that of gallic acid, and therefore remains at the bottom, while the other may be drawn off.

Pure tannic acid is colorless and inodorous, has a purely astringent taste without bitterness, and may be preserved without change in the solid state. It is very soluble in water, and the solution reddens litmus, and decomposes alkaline carbonates with effervescence, thus leaving no doubt of its acidity. Alcohol and ether also dissolve tannic acid, but more sparingly than water, especially when anhydrous. Solutions of tannic acid do not affect pure protosalts of iron, but strike a deep blue precipitate with the persalts.

Tannic acid combines with the skins of animals, forming an insoluble compound which does not putrefy. This is the basis of most kinds of *leather;* and the art of tanning consists in promoting the union of these substances.

Tannic acid, like the gallic, forms a black compound with the persalts of iron; but it is easily distinguished from that acid by forming a precipitate with gelatine.

ULMIC ACID.

951. This acid is formed by the long exposure of wood to the action of air and moisture. It is considered the same as the *geic acid* of Berzelius, which is obtained from soil by digesting it with water. It seems to be closely related to *humus* and to *humic acid*, which are found also in soils, and are supposed to contribute much to their fertility. They all require further investigation.

STEARIC ACID.

952. Stearic acid (from *στεαρ*, *tallow*,) is obtained by boiling stearine with potassa and decomposing the product with warm dilute hydrochloric acid. The stearic acid which precipitates is to be well washed with pure water.

953. The stearine used in this process is an essential ingredient in all solid fats, as mutton-suet. It is obtained from this substance by digesting and washing in ether, or by melting it with six times its weight of ether and subjecting it to strong pressure.

954. Stearic acid is without taste or odor; it melts at 158°, and on cooling forms a white crystaline mass which may be pulverized. Its specific gravity is 1.01. Made into candles it burns like wax, with a clear, white flame.

Stearic acid unites with bases forming numerous salts, which possess little interest except in their chemical history. The neutral stearate of potash is soluble in hot alcohol, and on cooling forms a white jelly, called *opodeldoc*.

OLEIC ACID.

955. Oleic acid (name from *ελαιον*, *oil*,) is obtained chiefly from liquid fixed oils that are not drying oils, but is contained in the various solid fats. To prepare the acid it is necessary first to procure oleine, which exists in large quantity in oils, especially in almond oil. This is done by dissolving the oil in boiling ether, and then subjecting the solution to a low temperature, by which the margarine contained in the oil is crystalized out; the ether is then readily separated by evaporation. The oleine thus formed, which is liquid even at 0°, is then to be heated with potassa, and the soap formed decomposed with dilute hydrochloric acid, and the oily oleic acid which separates washed well with water and dried with chloride of calcium.

Oleic acid in its pure state has a specific gravity of 0.898; it has little taste or odor, but a decidedly acid reaction. It crystalizes at temperatures below 32°.

This acid unites readily with bases forming salts, which, however, possess little interest.

MARGARIC ACID.

956. This acid, the name of which is derived from *μαργαριτης*, a *pearl*, like the stearic and oleic, is obtained from the various oils and fats. It bears a close resemblance to stearic acid, and its salts are very similar to the stearates.

Carbazotic acid is obtained by the action of nitric acid upon indigo, and several animal and vegetable substances.

Lactic acid was first discovered in sour milk, but it is also obtained from the juice of the beet root.

Racemic acid is intimately associated with tartaric acid in the grape, from which it is separated by a particular process.

Moric or *moroxylic acid* is found in the bark of the white mulberry (*morus alba*).

Valerianic acid is obtained from the root of valerian (*valeriana officinalis*). It is liquid at common temperatures, and boils at 270°.

Rocellic acid is found in the *rocella tinctorum*, and other vegetables.

Igasuric acid is obtained from the *nux vomica*.

Other vegetable acids are the *mucic mellitic*, *lactucic*, *croconic*, *kinic*, *caincic*, *cremaric*, *pectic*, *boletic*, *zumic*, *rhodizonic*, *benzilic*, *formic*, *melanic*, *esculic*, *xanthic*, *aldehydic*, *komelic*, *itaconitic*, *maleic*, *fumasic*, *cocoic*, *sericic*, *palmitic*, *pimelic*, *adipic*, &c. &c. &c.

The compound acids will be described hereafter, so far as is necessary for our purpose.

SECTION III.

VEGETABLE ALKALIES.

957. **Under** this title are comprehended those proximate vegetable principles which exist naturally in plants, and possess distinct alkaline properties. Their existence was first recognized early in the present century. They are capable of neutralizing even the strongest acids, and are distinguished from most other substances of vegetable origin by containing nitrogen.

They never exist in an insulated state in the plants which contain them; but they are apparently in every case combined with an acid, with which they form salts more or less soluble in water. These alkalies, in their separate states, are for the most part very insoluble in water, and of sparing solubility in cold alcohol; but they are all readily dissolved by that fluid at a boiling temperature, being deposited from the solution, commonly in the form of crystals, on cooling. Most of the salts are far more soluble in water than the alkalies themselves, and several of them are remarkable for their solubility.

958. The following are some of the more important vegetable alkalies:

Names.	*Equiv.*	*Symbols.*
Morphia	296.35	$NC_{35}H_{20}O_6$
Quinia	164.55	$NC_{20}H_{12}O_2$
Cinchonia	156.55	$NC_{20}H_{12}O$
Narcotina	421.67	$NC_{46}H_{22}O_{13}$
Strychnia	351.58	$N_2C_{44}H_{22}O_4$

MORPHIA.

959. This alkali is the chief medicinal agent of opium, in which it exists combined with meconic and sulphuric acids and associated with several other substances, especially with narcotina, gummy, resinous, and extractive coloring matters, &c.

960. To prepare it, one part of opium, eight of water, and one of hydrochloric acid, are digested together for six hours, and the residue which is left twice more treated in the same manner. The solution thus obtained is then saturated with common salt, and the precipitate which forms by standing collected on a filter and digested in aqua ammonia for twenty-four hours. A precipitate is now formed, which, when collected by a filter, is to be washed with water, dried, and digested in strong alcohol, which dissolves the morphia, and is itself easily separated by evaporation.

In this process, the object of using the common salt is to separate the narcotine always contained in opium, while the meconic acid, codcine, &c., are removed by dissolving in ammonia, and subsequently in alcohol.

961. Morphia readily crystalizes from its alcoholic solution in small right rhombic prisms. In its pure state it has scarcely any taste; but when rendered soluble by combining with an acid or by solution in alcohol, it is intensely bitter. It has an

alkaline reaction, and combines with acids, forming neutral salts, which are far more soluble in water than morphia itself, and for the most part are capable of crystalizing. Solutions of pure potassa and soda dissolve it, as in some measure does ammonia also.

The salts of morphia are prepared by dissolving it in dilute acids and evaporating the solution.

962. *Sulphate of Morphia.*—This salt crystalizes in groups of acicular crystals, which dissolve in twice their weight of water. They always contain 6 eq. of water to each equivalent of the salt. It is used in medicine.

Bisulphate of morphia has an acid reaction. It is little known.

963. *Hydrochlorate of Morphia.*—This salt is much used in medicine. It may be formed by the direct union of anhydrous morphia and hydrochloric acid gas. It is generally seen in beautiful acicular crystals, which are anhydrous.

964. *Acetate of Morphia.*—Acetate of morphia is formed by dissolving the alkali in acetic acid, or by decomposing the hydrochlorate by acetate of lead.

965. *Meconate of Morphia* is probably the active principle in opium. From all its salts morphia may be precipitated by tannic acid and by ammonia.

NARCOTINA.

966. Narcotina was first described by Derosne in 1803, and was therefore long called *salt of Derosne*. It is obtained from opium. It crystalizes in colorless rhombic prisms, which fuse at a temperature of 338°, and congeal again on cooling.

Narcotina is easily distinguished from morphia by being soluble in ether, and in solutions of the caustic alkalies and earths. Its salts are of little interest.

CINCHONIA AND QUINIA.

967. These two vegetable alkalies are almost always found associated together in certain kinds of bark which have long been distinguished for their active medicinal properties. There are several varieties of the bark, but all have been called Peruvian bark, from the place whence most of it is obtained.

968. These principles, though very analogous, are distinctly different, standing in the same relation to each other as potassa and soda. Cinchonia exists in the *Cinchona condaminea*, or pale bark; quinia, often with a little cinchonia, is present in C. *cordifolia*, or yellow bark; and they are both contained in C. *oblongifolia*, or red bark. One of the easiest processes for preparing them, is to take up the soluble parts of the bark by hot water acidulated with hydrochloric acid, concentrate the solution, and then digest with successively added portions of slaked lime, until the liquid is distinctly alkaline. The precipitate is carefully collected, and the vegetable alkali separated from it by boiling alcohol. Slight modifications of the method

have been proposed. From one pound of yellow bark, Moreton procured 80 grains of quinia, which is nearly 1.4 per cent., but the quantity obtained from different varieties of bark is very variable.

969. *Cinchonia.*—Pure cinchonia crystalizes in colorless quadrilateral prisms, which are anhydrous, require 2500 times their weight of boiling water for solution, and are insoluble in cold water. Its proper menstruum is boiling alcohol; but it is dissolved in small quantity by oils and ether. Its taste is bitter, though slow in being perceived, on account of its insolubility; but when the alkali is dissolved by alcohol or an acid, the bitterness is very powerful, and accompanied by the flavor of cinchona bark. Its alkaline properties are exceedingly well marked, since it neutralizes the strongest acids. The sulphate, hydrochlorate, nitrate, and acetate of cinchonia are soluble in water, and the sulphate crystalizes in very short six-sided prisms derived from an oblique rhomboidal prism. It commonly occurs in twin crystals.

970. *Sulphates of Cinchonia.*—There are two sulphates of cinchonia, the bibasic and the neutral. They very much resemble the corresponding salts of quinia. The same may be said of the other salts of cinchonia.

971. *Quinia.*—This substance possesses much greater interest than the preceding. It is separated from cinchonia by dissolving their mixed sulphates in alcohol, from which crystals of sulphate of quinia are deposited, while the other salt remains in solution.

972. *Sulphates of Quinia.*—There are two of these salts, the bibasic and the neutral sulphates. The bibasic or disulphate of quinia is extensively used in medicine, and is often called simply *quinine.* Its use as a specific in intermittent fever is well known. It crystalizes in delicate white needles, having the appearance of amianthus, has a very bitter taste, and is less soluble in water than sulphate of cinchonia. It is freely dissolved by boiling alcohol, and is neutral to test paper. It is composed of 2 equivalents of quinia, 1 equivalent of sulphuric acid, and 8 equivalents of water.

The neutral sulphate crystalizes in quadrangular prisms, which readily effloresce in the open air, and are soluble in ten times their weight of water at 60°.

973. Sulphate of quinia, from its commercial value, is frequently adulterated. The substances commonly employed for the purpose are sugar, gum, starch, ammoniacal salts, and earthy salts, such as sulphate of lime and magnesia, or acetate of lime. Pure sulphate of quinia, when deprived of its water of crystalization by a heat of 212°, should lose only from 8 to 10 per cent. of water. Sugar may be detected by dissolving the suspected salt in water, and adding precisely so much carbonate of potassa as will precipitate the quinia. The taste of the sugar, no longer obscured by the intense bitter of the quinia, will generally be perceived; and it may

be separated from the sulphate of potassa, by evaporating gently to dryness, and dissolving the sugar by boiling alcohol. Gum and starch are left when the impure sulphate of quinia is digested in strong alcohol. Ammoniacal salts are discovered by the strong odor of ammonia, which may be observed when the sulphate is put into a warm solution of potassa. Earthy salts may be detected by burning a portion of the sulphate.

974. *Strychnia* is an alkaline substance obtained from the nux vomica and St. Ignatius' bean. It is also found in the famous Upas of the Island of Java. It is one of the most violent vegetable poisons known. Its salts, in consequence of their greater solubility, are more active than the alkali itself.

Brucia is nearly allied to the preceding substance, and is always found associated with it.

975. *Veratria*, obtained from the *veratrum album*; *Picrotoxia*, from *coculus indicus*; *Solania*, from the *solanum dulcamara*; *Sanguinaria*, from the *sanguinaria canadensis*; *Corydala*, *Delphia*, *Cynopia*, &c., are classed with the vegetable alkalies.

Various other plants, as *conium maculatum*, *cicuta maculata*, *atropa belladona*, *datura stramonium*, &c., owe their active properties in all probability to peculiar alkalies contained in them.

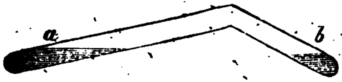
SECTION IV.

CYANOGEN AND ITS COMPOUNDS.

976. Cyanogen is probably the most important, as well as the best known in its various relations, of all the compound radicals. It is therefore made the subject of a separate section.

The mode of preparing it has already been given (470), and some description of the substance. At ordinary temperatures it is gaseous (471), but as before stated may easily be converted into a liquid by the moderate pressure of 3.6 atmospheres.

Fig. 87.



977. This may be done as follows: Let a small quantity of cyanide of silver be introduced into a strong glass tube, bent, as in figure 87, and hermetically sealed. It is then to be held horizontally, and the heat of a lamp applied at the extremity *a*, containing the cyanide of silver. The other extremity *b* is to be kept cool; and in a short time the liquid cyanogen will be seen to collect in it.

978. The following table exhibits the names, composition, &c., of some of the more important compounds of this substance, which are described in this work:

Names.	*Equiv.*	*Symbols.*
Cyanogen	26.39	NC_2 or Cy
Cyanic acid	34.39	NC_2O or CyO
Fulminic acid	68.78	Cy_2O_2
Cyanuric acid	103.17	Cy_3O_3
Hydrocyanic acid	27.39	CyH

Names.	*Equiv.*	*Symbols.*
Protocyanide of iron	54.39	FeCy
Sesquicyanide of iron	135.17	Fe_2Cy_3
Cyanide of silver	134.39	AgCy
Ferrocyanide of potassium	185.47	FeCy+2KCy
Sesquiferrocyanide of iron	——	$3FeCy+2Fe_2Cy_3$
Bisulphuret of cyanogen	58.59	CyS_2 or Csy

Numerous other compounds of this radical must be entirely omitted.

979. *Cyanic Acid.*—This acid is formed by causing a current of cyanogen to pass through a solution of potassa; water is decomposed, and a cyanide and a cyanate of potassa are formed; and from the cyanate the acid may by proper means be separated. It may also be procured by various other means.

980. This acid when pure is a transparent liquid at ordinary temperatures, is very volatile, and has a pungent odor like acetic acid. It forms with bases numerous salts, which however do not require description here.

981. *Fulminic Acid.*—This acid has received its present name in consequence of its forming powerfully detonating or fulminating compounds when united with several bases, and particularly with the oxides of mercury and silver. It is formed by the action which takes place when a proper proportion of alcohol is poured into a strongly acid solution of mercury or silver, and unites immediately with the oxide of the metal used, from which it may be separated by digesting it with potassa, forming a fulminate of potassa. It cannot be obtained in a free state.

Fulminic acid is bibasic, and forms two series of salts, the neutral which contains 2 eq. of fixed base, and the acid salts which contain 1 eq. of fixed base and 1 eq. of water.

981. *Fulminate of Mercury.*—Fulminate of mercury was first formed by Howard in the year 1800. It is prepared by dissolving 100 grains of mercury in a measured ounce and a half of nitric acid of specific gravity 1.3; and adding, when the solution has become cold, two ounces by measure of alcohol, the density of which is 0.849. The mixture is then heated till moderately brisk effervescence takes place, during which the fulminating compound is generated.

A much better method is that recommended by Professor Silliman (Chemistry, II, 322). Single aquafortis is added to mercury in excess, in a tumbler, and allowed to stand over-night in the cold. The solution thus formed, after being agitated to mix the parts equally, is poured into a tall glass, as a quart tumbler or earthen pitcher, with an equal quantity, by measure, of the strongest double aquafortis. A very little alcohol should now be added, and in a few minutes slight explosions will begin to be heard, and violent effervescence will then at once commence, which should be checked by the addition of more alcohol. The fumes should never be allowed to become red, nor should so much alcohol be added at any time as to cause the effervescence entirely to cease. About two measures of alcohol will be required to one of the acid. The precipitate begins to form immediately with the effervescence, and when it ceases to increase, the action should be stopped by pouring in cold water; and the powder collected in a filter and washed. Not more than two fluid ounces of the solution of mercury should ever be used at a time.

982. The salt as thus prepared often contains a little metallic mercury, from which it may be freed by dissolving it in boiling water and recrystalizing. When dry it explodes with great violence by a slight blow with a hard substance, or by friction. It is much used in the manufacture of percussion caps for fire-arms. For this purpose it is made into a paste with nitre, in the ratio of 10 parts of the former to 6 parts of the latter.

983. *Fulminate of Silver.*—To form this substance, a twelve and a half cent piece may be dissolved in two ounces of nitric acid, diluted with an equal measure of *distilled* water, by the aid of heat; and when cold, two ounces of common alcohol added. The heat of a lamp is then to be applied, but removed as soon as effervescence commences; the fulminate is gradually deposited in beautiful snow-white crystals, which are to be collected on a filter and carefully washed with distilled water.

Fulminate of silver is sparingly soluble in cold water, but readily dissolves in 36 times its weight of boiling water. It is one of the most explosive compounds known, and should never be formed or handled but with extreme caution. It is very improperly made the basis of a small toy called a *torpedo*, which consists of a little of the salt mixed with some gravel and done up in paper. It explodes merely by being thrown upon a hard substance.

984. *Fulminate of Zinc* is formed by digesting metallic zinc in solution of fulminate of mercury.

985. *Cyanuric Acid.*—Cyanuric acid is produced by a variety of means. It derives its chief importance from being isomeric with the two preceding acids, as will be seen by consulting the table above (978). It is tribasic, while fulminic acid is bibasic, and cyanic acid monobasic.

986. *Hydrocyanic or Prussic Acid.*—This compound is a constituent of water distilled from the leaves and blossoms of the peach and other stone fruits, and is formed artificially by the destructive distillation of many bodies which contain nitrogen, by the decomposition of the metallic cyanides, &c.

Pure hydrocyanic acid is a limpid, colorless liquid, of a strong odor, similar to that of peach blossoms. It excites at first a sensation of coolness on the tongue, which is soon followed by heat; but when diluted, it has the flavor of bitter almonds. Its specific gravity at 45° is 0.70. Its point of ebullition is 80°, and at 5° it congeals. When a drop of it is placed on a piece of glass, it becomes solid, because the cold produced by the evaporation of one portion is so great as to freeze the remainder. It unites with water and alcohol in every proportion.

987. Pure hydrocyanic acid is a powerful poison, producing in poisonous doses insensibility and convulsions, which are

speedily followed by death. A single drop of it placed on the tongue of a dog causes death in the course of a very few seconds; and small animals, when confined in its vapor, are rapidly destroyed. On inspiring the vapor, diluted with atmospheric air, headache and giddiness supervene; and for this reason the pure acid should not be made in close apartments during warm weather. Its effects are best counteracted by diffusible stimulants, and of such remedies solution of ammonia appears to be the most beneficial. The aqueous solution of chlorine may be used as an antidote, which decomposes hydrocyanic acid instantly, with formation of hydrochloric acid. In some experiments, recently described, symptoms of poisoning, induced by hydrocyanic acid applied to the globe of the eye, ceased on the internal administration of chlorine. It would hence appear that both substances were absorbed into the circulating fluids, and there reacted on each other.

988. Pure hydrocyanic acid, even when excluded from air and moisture, is very liable to spontaneous decomposition, owing to the strong tendency of its elements to form new combinations. This sometimes commences in a few hours after its formation. Its presence in a free state may generally be known by its odor.

This acid is considerably used in medicine, of course in a very dilute state. The prussic acid of commerce usually contains only from 1 to 4 per cent. of the acid, the rest being water.

989. *Cyanide of Iron.*—This substance is distinguished for entering into combination with other metallic cyanides, forming the class of bodies called *ferro-cyanides.* It seems doubtful whether it has ever been obtained in a state of purity.

990. *Sesquicyanide of Iron.*—It is not known in a free state. Like the protocyanide of iron, it forms numerous compounds with other bodies.

991. *Cyanide of Silver.*—Cyanide of silver falls as a curdy white precipitate when hydrocyanic acid is mixed with a solution of any salt of silver. It is used in preparing cyanogen.

992. *Ferrocyanide of Potassium.*—This compound is found in commerce in a state of great purity. It is generally seen in large yellow crystals or crystaline masses, and is called *Prussiate of potash,* or sometimes *triple prussiate of potash.* It is prepared on a large scale by gently igniting potash with animal matters, such as dried blood, and the horns and hoofs of animals, when cyanide of potassium, along with some ferrocyanide, if iron be present, is generated. The soluble parts are taken up in water, and sulphate of protoxide of iron is added, until the Prussian blue which is formed ceases to be decomposed by the free potassa contained in the solution. The ferro-cyanide of potassium is then set to crystalize, and is purified from sulphate of potassa by repeated crystalization.

This substance is perfectly neutral to test paper, and crystalizes readily in large transparent four-sided, nearly square, tabular crystals, derived from an acute rhombic octohedron, the apices of which are deeply truncated. It has a lemon-yellow color, no odor, a slightly bitter taste, quite different from that of hydrocyanic acid, is insoluble in alcohol, but dissolves in less than its weight of hot water.

This salt is much employed in preparing by double decomposition the insoluble ferrocyanides; and as the precipitates have in several instances very characteristic colors, ferrocyanide of potassium is much employed as a test.

It is also used very extensively in the arts, especially in calico-printing. Of late it has been made use of in case-hardening iron (677), but it is said it cannot always be employed for this purpose, as it is apt to corrode the surface of the metal.

993. *Sesquiferrocyanide of Iron.*—This substance was accidentally discovered at Berlin, Prussia, in 1710, from which, and from its beautiful blue color, it became generally known under the name of *Berlin* or *Prussian blue.* It has sometimes been considered as a ferrocyanide of the peroxide of iron; but as will be seen by referring to the table above given (978), it is a compound of 3 eq. of protocyanide of iron, and 2 eq. of the sesquicyanide of iron. A ferro-cyanide gives Prussian blue with a salt of the *per*oxide of iron, because by interchange of their elements sesquicyanide of iron is generated.

*Proto*xide of iron does not produce the same effect, because when it exchanges elements with cyanide of potassium, protocyanide and not sesquicyanide of iron is generated.

To prepare Prussian blue, add ferro-cyanide of potassium to sulphate of the peroxide of iron, the latter being in excess and acidulated with sulphuric acid, and both largely diluted. A blue precipitate will soon subside, from which the supernatant liquid should be drawn with a syphon, and the vessel again immediately filled with cold water, slightly acidulated with sulphuric acid. After subsidence the water should be again drawn off as before, and the process several times repeated, the last time with pure water. The precipitate is then to be dried in a warm place. The immediate washing is important.

The Prussian blue of commerce is prepared by fusing animal matters with pearlash so as to form cyanide of potassium, which is mixed in solution with green vitriol and alum. A dirty green precipitate ensues, consisting of black oxide of iron, protocyanide of iron, and alumina, which by exposure to the air becomes blue.

This substance is much used as a pigment, but its color is not permanent. Exposed to the direct light of the sun, it even becomes white, but in the dark the color is again restored. The Prussian blue of commerce is very impure.

994. *Bisulphuret of Cyanogen.*—This is also called *sulpho-cyanogen.* It is prepared by saturating a concentrated solution of some metallic sulpho cyanide with chlorine, or by heating it with nitric acid. It falls in the form of a deep-yellow powder. By the action of heat it is decomposed, and other important compounds formed (910).

995. The above are but a very few of the compounds of cyanogen, but as many as the object of this work will allow us to describe. Several others have been named in the table of compound radicals already given (908); and for a full discussion of the subject the student is referred to that of the late edition of Turner's work, or to Kane.

SECTION V.

INTERMEDIATE AND NEUTRAL PRINCIPLES.

996. It is proposed to introduce in this section a large class of substances which possess a considerable variety of character, including nearly all those usually placed in other more extended works in the two families of *intermediate* and *neutral* bodies. Some of these substances act the part of acids, and others that of bases, but still they differ so widely in many of their properties from the bodies described in the second and third sections of this chapter, as not to be entitled to a place among them. Many appear to be neutral in reality as they are in name.

STARCH.

997. Starch exists abundantly in the vegetable kingdom, being one of the chief ingredients of most varieties of grain, of some roots, such as the potato, and of the kernels of leguminous plants. It is easily procured by letting a small current of water fall upon the dough of wheat flour inclosed in a piece of linen, and subjecting it at the same time to pressure between the fingers, until the liquid passes off quite clear. The gluten of the flour is left in a pure state, the saccharine and mucilaginous matters are dissolved, and the starch is washed away mechanically, being deposited from the water on standing in the form of a white powder. The starch of commerce is obtained by an analogous process from the grain of wheat and from the potato; but in the preparation of wheat starch, the water containing the soluble and insoluble parts of the grain is allowed to ferment, whereby acetic acid is generated, which dissolves the glutinous portion, and thus facilitates its separation from the starch.

998. Starch is insipid and inodorous, of a white color, and is insoluble in alcohol, ether, and cold water. It does not crystalize; but it is commonly found in the shops in six-sided columns of considerable regularity, a form occasioned by the contraction which it suffers in drying. Boiling water acts upon it readily, converting it into a tenacious, bulky jelly, which is employed for stiffening linen. In a large quantity of hot water, it is dissolved completely, and is not deposited on cooling. The best test of starch, by which it is distinguished from all other substances, is iodine. This principle forms with starch, whether

solid or in solution, a blue compound which is insoluble in cold water; with hot water it forms a colorless solution, which deposites the blue compound as it cools; but when boiled with water, iodine acts upon the elements of the starch, hydriodic acid is formed, and then on cooling the blue iodide of starch is not reproduced.

999. If starch is heated quite hot for some time, it is converted into a peculiar substance which is very soluble in cold water called *British gum.*

1000. There are several substances known in commerce, which are merely varieties of starch. The *Indian arrow-root*, which is prepared from the root of the *maranta arundinacea*, has all the characters of pure starch. *Sago*, obtained from the cellular substance of an East India palm-tree (*sagus farinifera*); and *tapioca* and *cassava* from the root of the *iatropha manihot*, are chemically the same substance. They both exist in the plants from which they are extracted in the form of starch. *Salep*, which is obtained from the *orchis mascula*, consists almost entirely of the substance called *bassorin*, together with a small quantity of gum and starch. The composition of starch is $C_{12}H_{10}O_{10}$.

GUM.

1001. This name is generally applied to those vegetable substances which are more or less soluble in water, but are insoluble in alcohol, and which, when boiled with about four times their weight of nitric acid, yield mucic acid.

The properties of gum are best studied in pure specimens of gum-arabic, of which it is the principal ingredient. It is colorless, transparent, inodorous, and insipid, and when dry it is very brittle, and has a vitreous fracture. When put into water, either hot or cold, it softens, and then dissolves, constituting mucilage. Its solubility is increased both by acids and alkalies.

The aqueous solution of gum may be preserved a considerable time without alteration; but at length it becomes sour, and exhales an odor of acetic acid, a change which takes place without exposure to the air, and must, therefore, be owing to a new arrangement of its own elements.

1002. The following are some of the most important gums:

Gum-Arabic.—This substance is the concrete juice of several species of the *mimosa*, or *acacia*, natives of Africa and Arabia. It occurs in small, rounded, transparent, friable grains, which are sometimes colorless, and at others, yellow, red, or brown. Its density is 1.355.

Gum-Senegal, the juice of the *acacia senegalensis*, contains exactly the same principles as gum-arabic. The mucilage of linseed, and probably of most of the mucilaginous seeds and plants, possesses the essential characters of gum-arabic.

Gum-Tragacanth, the juice of the *astragalus gummifer*, differs essentially from the pure gums.

The gum which issues from several trees of the genus *prunus*, as from the peach, plum, apricot, and cherry-tree (*p. cerasus*), is found to be identical in composition with gum-arabic

It differs, however, in being insoluble in cold water; but when boiled in that liquid it is dissolved, and the solution has all the characters of pure mucilage.

The composition of the different varieties of gum is believed to be $C_{12}H_{11}O_{11}$.

SUGAR.

1003. There are several varieties of sugar, the chief of which are common or cane sugar, and grape sugar. Other sugars are the *sugar of milk*, *mushroom sugar*, &c. The composition of the first two will be seen from the following table:

Names.	*Equiv.*	*Symbols.*
Cane sugar	154.44	$C_{12}H_9O_9$
Grape sugar	172.44	$C_{12}H_{11}O_{11}$

1004. *Cane Sugar.*—Common or cane sugar is obtained in this country in large quantities from the sap of the *acer saccharinum* or *sugar maple.* In France and Germany, and to some extent in this country, it is also manufactured from the beet root, which contains it in considerable quantity. But most of the sugar at present used in Europe and America is obtained from the sugar-cane (*Arundo saccharifera*), which contains it in a greater quantity than any other plant. The process, as practised in the West India Islands, consists in evaporating the juice of the ripe cane by a moderate and cautious ebullition, until it has attained a proper degree of consistence for crystalizing. During this operation lime-water is added, partly for the purpose of neutralizing free acid, and partly to facilitate the separation of extractive and other vegetable matters, which unite with the lime and rise as a scum to the surface. When the syrup is sufficiently concentrated, it is drawn off into shallow wooden coolers, where it becomes a soft solid composed of loose crystaline grains. It is then put into barrels with holes in the bottom, through which a black ropy juice, called *molasses* or *treacle*, gradually drops, leaving the crystalized sugar comparatively white and dry. In this state it constitutes raw or muscovado sugar.

1005. Raw sugar is further purified by boiling a solution of it with white of eggs, or the serum of bullock's blood, lime-water being generally employed at the same time. When properly concentrated, the clarified juice is received in conical earthen vessels, the apex of which is undermost, in order that the fluid parts may collect there, and be afterwards drawn off by the removal of a plug. In this state it is loaf or refined sugar. In the process of refining sugar, it is important to concentrate the syrup at a low temperature; and on this account a very great improvement was introduced some years ago by conducting the evaporation *in vacuo.*

1006. Pure sugar is solid, white, inodorous, and of a very agreeable taste. It is hard and brittle, and when two pieces are rubbed against each other in the dark, phosphorescence is observed. It crystalizes in the form of four or six-sided prisms, beveled at the extremities. The crystals are best made by fixing threads in syrup, which is allowed to evaporate spontaneously in a warm room; and the crystalization is promoted by adding spirit of wine.

Sugar undergoes no change on exposure to the air; for the deliquescent property of raw sugar is owing to impurities. It is soluble in one-third of its weight of cold, and to almost any extent in hot water. It is soluble in about four times its weight of boiling alcohol, and the saturated solution, by cooling and spontaneous evaporation, deposites large crystals. When the aqueous solution of sugar is mixed with yeast, it undergoes the vinous fermentation, the theory of which will be explained hereafter.

Sugar unites with the alkalies and alkaline earths, forming compounds in which the taste of the sugar is greatly injured; but it may be obtained again unchanged by neutralizing with sulphuric acid, and dissolving the sugar in alcohol.

When sugar is heated to 400° or 420°, it gives up a portion of water, and is converted into a substance called *caramel*. If a strong solution is kept several days near its boiling point, it is gradually changed into uncrystalizable sugar.

1007. *Grape Sugar.*—This sugar much resembles the preceding, and is more generally diffused in nature. It gives to most fruits their sweet taste, and forms the solid part of honey. It is most easily procured from the grape, from which circumstance it receives its name. Dumas proposes to call it *Glucose*.

This substance is sometimes produced in the animal system, and is found in their urine in certain forms of disease, as in diabetes; and may be prepared from a variety of substances, as starch, gum, cane sugar, woody fibre, &c.

1008. To prepare grape sugar from starch, 1 part of potato starch, 4 parts of water, and $\frac{1}{50}$ of sulphuric acid are to be boiled for 36 or 40 hours, the water that evaporates being replaced. The acid is then to be removed by chalk, and the solution evaporated until the syrup has obtained a sufficient consistence to crystalize on cooling.

The same effect is produced upon starch by mixing with it an infusion of malt, and allowing it to stand in the air a few hours. A substance called *dextrine* is first formed, which passes into grape sugar. This change is produced by the catalytic influence of a principle called *diastase*, which exists in malt.

1009. To convert woody fibre into grape sugar, small pieces of paper or linen are gradually to be moistened with their own weight of sulphuric acid, and allowed to stand 24 hours. The mass is then to be diluted with water and boiled for some 10 hours; and the acid being then removed by chalk, and the solution evaporated, the sugar crystalizes.

Grape sugar is less soluble in water than cane sugar, but is sweeter to the taste. Its specific gravity is 1.38. It is capable, like cane sugar, of uniting with the earths and some metallic oxides, but the compounds are different.

1010. The action of the sulphuric acid in the above processes for preparing this sugar, seems to be merely to cause the absorption by the starch, or woody fibre, of oxygen and hydrogen, in the ratio in which they unite to form water. The composition of starch is $C_{12}H_{10}O_{10}$, and that of woody fibre $C_{12}H_8O_8$; the former is therefore converted into grape sugar by the absorption of a single eq. and the latter 3 eq. of water. The quantity of sugar produced is always greater than that of the starch or woody fibre employed. From 100 parts of linen rags 114 of sugar have been formed.

1011. *Sugar of Milk* ($C_{24}H_{19}O_{19}$) is obtained by the evaporation of whey, purifying with animal charcoal, and crystalizing.

1012. *Manna.*—This substance is the concrete juice of several species of the ash, particularly the *Fraxinus ornus.* It is indebted for its sweetness to a distinct principle called *mannite* ($C_6H_7O_6$). Mannite is also found in other substances. The sugar contained in juice of the beet is rapidly converted into mannite, if it is allowed to stand but a short time in the pulp after grinding the beet.

ALCOHOL.

1013. Alcohol is the intoxicating ingredient of every variety of spiritous and vinous liquors. It does not exist ready formed in plants, but is produced from vegetable substances during the vinous fermentation, the theory of which will be hereafter explained. It is sometimes called *spirits of wine.* Its composition is $C_4H_6O_2$, and it may be considered, as will hereafter appear, as a hydrate of oxide of ethule.

1014. It may readily be procured by distilling any ardent spirit, as whiskey, or brandy. Common alcohol, or rectified spirits of wine, usually contains from 65 to 70 per cent. of pure alcohol, the rest being water: it has a specific gravity of 0.88 or 0.90. The most highly rectified alcohol, which contains about 90 per cent. of alcohol, has a specific gravity of 0.84. To separate the remaining water, powdered carbonate of potassa, previously heated to expel any water it may contain, is introduced; which is very soluble in water, but not in alcohol; the heavy solution of carbonate of potassa in water sinks to the bottom, while the lighter alcohol remains at top, and may be decanted. The same effect is produced by pouring common alcohol into bladders, and hanging them several days in the air. The water exudes through the membrane and evaporates, while the alcohol is retained. By either of these processes it may be brought to 98 per cent. Absolute alcohol is obtained by distilling it from chloride of calcium.

1015. Pure, anhydrous, or absolute alcohol, has a specific gravity of 0.79, and boils at 172°, but has not been frozen by any cold yet produced.

Alcohol is highly inflammable, and burns with a lambent yellowish-blue flame. Its color varies considerably with the strength of the alcohol, the blue tint predominating when it is strong, and the yellow when it is diluted. Its combustion is not attended with the least degree of smoke, and the sole products are water and carbonic acid.

Alcohol unites with water in every proportion. The act of combining is usually attended with diminution of volume, so that a mixture of 50 measures of alcohol and 50 of water occupies less than 100 measures. Owing to this circumstance, the action is accompanied with increase of temperature. Since the density of the mixture increases as the water predominates, the strength of the spirit may be estimated by its specific gravity. Equal weights of absolute alcohol and water constitute *proof spirit*, the density of which is 0.92.

1016. Of the salifiable bases alcohol can alone dissolve potassa, soda, lithia, ammonia, and the vegetable alkalies. None of the earths or other metallic oxides are dissolved by it. Most of the acids attack it by the aid of heat, giving rise to a class of bodies to which the name of *ether* is applied. All the salts which are either insoluble, or sparingly soluble in water, are insoluble in alcohol. The efflorescent salts are, likewise, for the most part, insoluble in this menstruum; but, on the contrary, it is capable of dissolving nearly all the deliquescent salts, except carbonate of potassa. Many of the vegetable principles, such as sugar, manna, camphor, resins, balsams and the essential oils, are soluble in alcohol.

The solubility of certain substances in alcohol appears owing to the formation of definite compounds, which are soluble in that liquid. This has been proved of the chlorides of calcium, manganese, and zinc, and of the nitrates of lime and magnesia. It appears that all these bodies unite with alcohol in definite proportion, and yield crystaline compounds, which are deliquescent and soluble both in water and alcohol. From their analogy to hydrates, they have been called *alcoates*.

1017. Alcohol exists ready formed in spirituous liquors, and may be separated by distilling them. According to many accurate experiments, brandy, rum, gin, and whiskey, contain from 51 to 54 per cent. of alcohol, of specific gravity 0.825. The stronger wines, such as Lissa, Raisin wine, Marsala, Port, Madeira, Sherry, Teneriffe, Malaga, and Vidonia, contain from 18 or 19 to 25 per cent. of alcohol. In Claret, Burgundy, Hock, Champagne, Hermitage, and Gooseberry wine, the quantity is from 12 to 17 per cent. In cider, perry, ale, and porter, the quantity varies from 4 to near 10 per cent.

1018. Alcohol, in some of its forms, is extensively used in the arts and in medicine, chiefly in consequence of its powerful solvent properties. Taken internally, it operates, as is well known, as a powerful stimulant; and various alarming diseases, often terminating in extreme moral degradation and death, attend its habitual use.

SPONTANEOUS CHANGES OF VEGETABLE MATTER—FERMENTATION.

1019. Organic substances, as we have already seen (898), usually have a strong tendency to spontaneous change, or putrefaction; that is, they tend to undergo a metamorphosis, by which the elements of a complex molecule group themselves, so as to form more intimate and more stable compounds, according to the special attractions of their elements, uncontrolled by the principle of life. In vegetable substances not containing nitrogen, this spontaneous change is termed *fermentation.* It exhibits in its progress three steps or stages, at the close of which definite compounds are formed; and from this circumstance, they are sometimes called the *saccharine,* the *vinous* or *alcoholic,* and the *acetic* fermentations.

1020. *Saccharine Fermentation.*—The only substance known to be subject to the saccharine fermentation is starch, though other substances, as we have seen (1008), may, by proper means, be converted into sugar. This kind of fermentation is well exemplified in the germination of seeds, as is seen in the malting of barley.

1021. This operation of malting consists in exposing grain (usually barley,) to the proper degree of heat and moisture, with the free accession of atmospheric air to produce incipient germination, and then suddenly checking it by elevating the temperature.

In this process, the grain passes through four distinct stages, called *steeping*, *couching*, *flooring*, and *kiln-drying.* In the first, it is steeped in water for about two days, when it absorbs moisture, softens, and swells considerably. It is then removed to the *couch-frame*, where it is laid in heaps, 30 inches in depth, for from 26 to 30 hours. In this situation the grain becomes warm, and acquires a disposition to germinate; but as the temperature, in such large heaps, would rise very unequally, and germination consequently be rapid in some portions and slow in others, the process of *flooring* is employed. This consists in laying the grain in strata a few inches thick on large airy but shaded floors, where it remains for about 12 or 14 days, until germination has advanced to the extent desired by the malster. During this interval the grain is frequently turned, in order that the temperature of the whole mass should be uniform, that each grain should be duly exposed to the air, and that the radicles of contiguous grains should not become entangled with each other. As soon as saccharine matter is freely developed, germination must be arrested; since, otherwise, being taken up as nutriment by the young plant, it would speedily disappear. Accordingly, the grain is removed to the kiln, where it is exposed to a temperature gradually rising from 100° to 160°, or rather higher; the object being, first, to dry the grain completely, and then to provide against any recurrence of germination by destroying the vitality of the plant. The most convenient mode of applying the heat is to place the grain on a metallic net-work, through which passes hot air issuing from a fire.

The product thus formed is called *malt.*

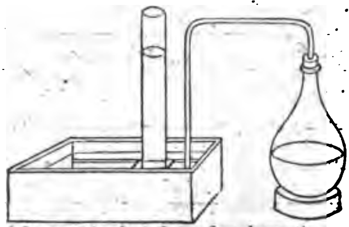
The ripening of fruit has also been regarded as an example of the saccharine fermentation, especially since many fruits, of which the pear and apple are examples, if gathered before their maturity, ripen by keeping; and by experiments upon other kinds of fruit, it has been found that, during the process of ripening, a large quantity of free acid contained in the green gradually disappears, and its place is occupied by sugar in the ripe fruit.

The sugar produced in this manner is always the variety called grape sugar.

1022. *Vinous Fermentation.*—Sugar is the only substance capable of undergoing the vinous fermentation, and the products of it are always alcohol and carbonic acid. The conditions required to produce this change in sugar are the presence with it of water, a certain temperature, and yeast, or some ferment.

1023. The best method of studying the process, so as to observe the phenomena and determine the nature of the change, is to place 1 part of sugar with about 5 parts of water in a glass flask furnished with a bent tube, the extremity of which opens under an inverted jar full of water or mercury, as in fig. 88; and after adding a little yeast, to expose the mixture to a temperature of about 70°. In a short time bubbles of gas begin to collect in the vicinity of the yeast, and the liquid is soon put into brisk motion, in consequence of the formation and disengagement of a large quantity of gaseous matter; the solution becomes turbid, its temperature rises, and froth collects upon its surface. After continuing for a few days, the evolution of gas begins to abate, and at length ceases altogether; the impurities gradually subside, and leave the liquor clear and transparent.

Fig. 88.



The only appreciable changes which are found to have occurred during the process are the disappearance of the sugar and a little water, and the formation of alcohol, which remains in the flask, and of carbonic acid gas, which is collected in the pneumatic apparatus. The theory of the process is founded on the fact that the sugar, which disappears, is very nearly equal to the united weights of the alcohol and carbonic acid; and hence the former, with the addition of a little water, is resolved into the two latter. Grape sugar, indeed, into which some suppose cane sugar is always converted before undergoing fermentation, does not require the addition of water, as the particles are in the proper ratio to form 2 atoms of alcohol and 4 of carbonic acid, for each atom of the sugar.

Though yeast, or some artificial ferment, is absolutely necessary to cause fermentation to commence in the solution of sugar, this is not required in the saccharine juices of plants, as those of the apple and the grape, which appear to contain the necessary principle within themselves.

1024. Though we have, thus far, spoken only of sugar and the juices of fruits as undergoing the vinous fermentation, yet it is well known that the various kinds of grain and other vegetable substances are susceptible of the same change. In this country, alcohol, and the various stimulating drinks that contain it, are manufactured from potatoes and grain.

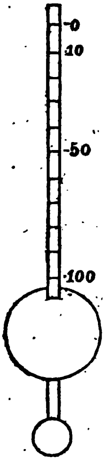
It admits of doubt, however, whether any substance besides sugar is capable of undergoing the vinous fermentation. The only other principle which is supposed to possess this property is starch; but from the facility with which this substance is converted into sugar, it is probable that the saccharine may precede the vinous fermentation.

1025. The various kinds of stimulating fluids, prepared by means of the vinous fermentation, are divisible into wines, which are formed from the juices of saccharine fruits, and the various kinds of ale and beer, produced from a decoction of the nutritive grains previously malted.

Beer is manufactured by digesting malt—previously ground with its weight of warm water for several hours, when the liquor, which is called *wort*, containing a large quantity of saccharine matter, starch, mucilage, &c., is run off, and boiled with hops. It is then cooled, and a little yeast added to induce fermentation, at the close of which the beer is fit for use. It usually contains much mucilaginous matter derived from the malt, and some free acid, the taste of which, however, is much disguised by the aromatic bitter of the hops.

1026. As it is important to have wort of the proper strength, an instrument called a *saccharometer* is used for the purpose. It is made of glass or metal. Its construction is seen in fig. 89. The upper bulb is filled with air, but the lower one is solid, or filled with some heavy substance, to make it stand upright in the liquid. Its weight is such, that in pure water it will sink to the point marked 0, but in a liquid of the specific gravity of 1.100, it is buoyed up to the mark 100. As the intermediate space is divided into 100 parts, the specific gravity may of course be determined very accurately.

Fig. 89.



The fermentative process which takes place in dough mixed with yeast, and on which depends the formation of good bread, has been supposed to be of a peculiar kind, and is sometimes designated by the name of *panary fermentation;* but it is found to be a proper vinous fermentation, alcohol being a constant product, which is expelled from the bread by the heat used in baking.

1027. *Acetic Fermentation.*—When any liquid which has undergone the vinous fermentation, or even pure alcohol diluted with water, is mixed with yeast, and exposed in a warm place to the open air, an intestine movement speedily commences, heat is developed, and the fluid becomes turbid from the deposition of a peculiar filamentous matter. Oxygen is absorbed from the atmosphere. These changes, after continuing for a certain time, cease spontaneously; the liquor becomes clear, and instead of alcohol, it is now found to contain acetic acid. This process is called the *acetic fermentation.*

The vinous may easily be made to terminate in the acetic fermentation; nay, the transition takes place so easily, that in many instances, in which it is important to prevent it, this is with difficulty effected. It is the uniform result, if the fermenting liquid be exposed to a warm temperature and to the open air; and the means by which it is avoided is by excluding the atmosphere, or by exposure to cold.

Certain methods of producing this fermentation, as well as the most important phenomena attending it, have already been explained, (926).

The spontaneous change that takes place in the juice of the beet when allowed to stand in the pulp, (1012), and in other substances, is sometimes called the *viscous fermentation.*

1028. The *putrefaction* of a substance, or its *putrefactive fermentation,* as it is sometimes termed, results in its complete destruction. It takes place more or less readily in all organic bodies which are constantly exposed to the action of air and moisture, at a temperature of from 50° to 100°.

THE ETHERS.

1029. This is the name applied to a numerous class of compounds, formed by distilling a mixture of alcohol with the different acids, and by other means. Usually, an ether is designated by the acid employed to form it; thus we have the sulphuric, nitric, oxalic, &c., ethers.

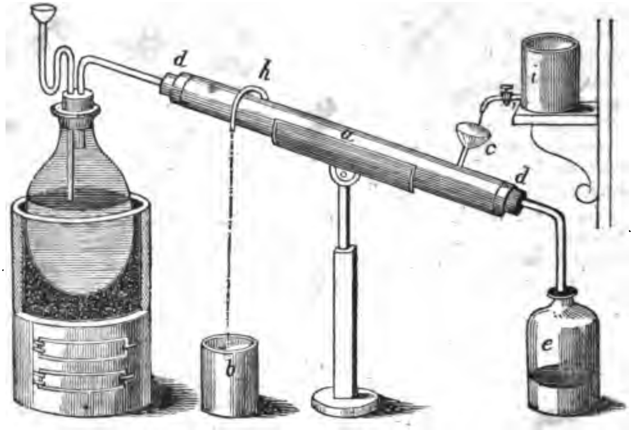
1030. The following are some of the most important of this class of bodies:

Names.	*Equiv.*	*Symbols.*
Sulphuric ether	37.48	C_4H_5O
Hydrochloric ether	64.90	C_4H_5Cl
Hyponitrous ether	75.63	C_4H_5O,NO_3
Oxalic ether	73.72	C_4H_5O,C_2O_3
Acetic ether	88.96	$C_4H_5O,C_4H_3O_3$

1031. *Sulphuric Ether.*—Sulphuric ether, mixed perhaps with a little alcohol, has been known for several centuries. It is prepared by distilling a mixture of alcohol and sulphuric acid, or by distilling alcohol with chloride of zinc, and by other means. The first method is always adopted in practice.

Equal parts of alcohol and sulphuric acid, being well mixed, care being taken to avoid any considerable rise of temperature, are to be introduced into a glass or copper vessel, to which heat may be applied by a sand-bath, as is represented in Fig. 90, or by other means. To condense the vapor of ether as it forms, the apparatus represented in the figure answers well, especially when a considerable quantity is to be formed; but for small operations, other more simple contrivances will secure the object perfectly. In this apparatus the condenser *dd* is a large glass tube, connected at one extremity with the vessel containing the mixture, and at the other with the receiver *e*, by means of small glass tubes bent in the proper manner. It is also inclosed in a tin-case, *a*, made water-tight at both ends by perforated corks, to receive a constant stream of cold water into the funnel *c*, from the vessel *i*. The water as it becomes heated escapes through the tube *h* into the vessel *b*. The supply of water is easily regulated, so as to be just sufficient to condense all the etherea vapor as it passes into the receiver. When the

Fig. 90.



action has continued some time, a new supply of alcohol may be introduced, a little at a time, through the crooked funnel.

1032. Sulphuric ether obtained in this manner is not perfectly pure, but contains a little alcohol and sulphurous acid, from which it may be freed by mixing it with caustic potassa, and distilling, and subsequently washing it with water, to remove the alcohol.

1033. As alcohol ($C_4H\ O_2$) may be considered as a hydrate of ether (C_4H_5O), it is evident that the only effect the acid has produced upon the alcohol, has been to deprive it of its water; but though this is the ultimate result, various other important chemical changes have been produced. When the acid and alcohol are first mixed, sulphate of ether ($SO_3+C_4H_5O$) (918) is formed, which consists of an atom of anhydrous sulphuric acid, and an atom of ether, the water both of the alcohol and acid being set free; and this, combining with another atom of the hydrous sulphuric acid, produces bisulphate of ether, the compound sulpho-vinic or althionic acid, $(2SO_3)+C_4H_5O+HO$. On the application of heat, the ether is expelled, and the sulphuric acid and water combine. Phosphoric and arsenic acids, produce upon alcohol under similar circumstances the same effect, as do also other acids capable of forming with ether compound acids. (918.)

1034. Pure ether is a colorless limpid liquid, of a hot pungent taste, and fragrant odor. Its sp. gr. is 0.72 at 60°, and under the atmospheric pressure, it boils at 96° or 98°, and at —40° in a vacuum. Its evaporation, from the rapidity with which it occurs, occasions intense cold. At —46° it freezes.

It dissolves in ten times its weight of water, but is miscible with alcohol and the volatile oils in all proportions.

Ether is highly inflammable, burning with a yellow flame, and formation of water and carbonic acid. With oxygen gas its vapor forms a mixture which explodes violently on the approach of flame, or by the electric spark.

1035. When a coil of platinum wire is heated to redness, and then suspended above the surface of ether contained in an open vessel, the wire instantly begins to glow, and continues in that state until all the ether is consumed. During this slow combustion, pungent acrid fumes are emitted, which, if received in a separate vessel, condense into a colorless liquid possessed of acid properties.

If ether is exposed to light in a vessel partially filled, and which is frequently opened, it gradually absorbs oxygen, and a portion of acetic acid is generated.

The solvent properties of ether are less extensive than those of alcohol. It dissolves the essential oils, resins, and most of the fatty principles. Some of the vegetable alkalies are soluble in it, and it dissolves ammonia; but it does not act on the fixed alkalies.

Ether combines with nearly all the acids, forming well-defined neutral salts, the *compound ethers*, as they are sometimes called. The hyponitrous, oxalic, &c. ethers, are examples.

1036. *Hydrochloric Ether.*—This substance may be prepared by distilling alcohol previously saturated with hydrochloric acid gas, and by other processes. The products are transmitted through tepid water, by which free alcohol and acid are absorbed, and the pure hydrochloric ether is then received in a vessel surrounded by ice or a freezing mixture.

Hydrochloric ether is a colorless liquid of a penetrating garlic odor, and a strong rather sweet taste. Its sp. gr. at 41° is 0.87; and it is so volatile that it boils at about 54°. It is neutral to test paper. When inflamed, as it issues from a small aperture, it burns with an emerald-green flame without smoke, yielding abundant vapors of hydrochloric acid.

Its composition, it will be recollected, is C_4H_5Cl.

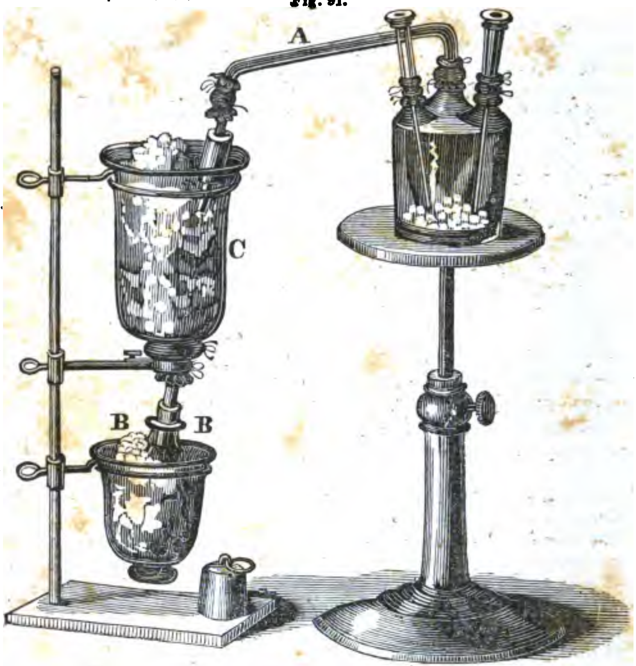
Other compounds of chlorine and ether are formed by passing a current of chlorine through alcohol, or by distilling mixtures of alcohol with common bleaching-salt, or other chloride. Their composition is not the same.

1037. *Hyponitrous Ether.*—This is often called *nitric* and *nitrous* ether; but the propriety of the term we use will be seen as we advance.

This ether is formed by distilling a mixture of strong nitric acid and alcohol; but from the violence of the reaction which takes place, much caution is necessary in the experimenter.

1038. Figure 91, from Hare's "Compendium," represents a good apparatus for this purpose. A common three-necked bottle is used to receive the acid and alcohol in small quantities at a time. In two of the tubulures are inserted glass tubes, a little enlarged at the top, which passing through perforated corks, terminate in capillar orifices near the bottom. By these the acid and alcohol are supplied as they are needed. From the central ubulure a bent tube, A, passes, and connects with a condenser surrounded y a freezing mixture in a receiver C, and a bottle BB to collect the ether as it forms. The bottle must also be surrounded by a freezing mixture.

Fig. 91.



The apparatus being in order, a little acid and alcohol are introduced, violent action at once commences, which is regulated by a supply of the acid or alcohol as occasion requires, and the ether collects in the bottle provided for the purpose. It may be purified from alcohol by means of water, and from water by chloride of calcium.

1039. Hyponitrous ether when pure is of a pale yellow color, and pungent odor, resembling that of apples. Its specific gravity is about 0.95, and it boils at about 61° or 62°. Its composition is $C_4H_5O+NO_3$ (918); that is, it is a compound of ether and hyponitrous acid. It is very liable to spontaneous decomposition when pure, but diluted with some six or eight times its weight of alcohol it is more permanent, and is much used in medicine, under the name of *sweet spirits of nitre.*

1040. *Oxalic Ether.*—To prepare oxalic ether, one part of alcohol, two parts of binoxalate of potassa, and two parts of sulphuric acid, are distilled with a quick fire. The product is then to be distilled from litharge to separate it from impurities. It is an oxalate of ether, $C_4H_5O+C_2O_3$.

Oxalic ether is a colorless liquid of an oily aspect, of an aromatic odor and a sp. gr. of 1.09 at 45°. It boils at 370°. It is neutral to test paper when pure, is sparingly soluble in water, and dissolves in every proportion in alcohol.

1041. *Acetic Ether.*—Acetic ether is formed when 16 parts of dry sugar of lead, 4½ of alcohol, and 6 of sulphuric acid, are distilled together. The product is purified in the usual manner.

It is a colorless inflammable liquid, of sp. gr. 0,89, and boils at 165°. It is an acetate of ether, $C_4H_5O+C_4H_3O_3$.

1042. Besides the above, there are numerous other similar compounds, which are properly called ethers, as belonging to the same natural family.

1043. *Theoretical Considerations.*—It would be improper here to omit some further theoretical remarks upon the constitution of the ethers, and their connection with other organic bodies, the nature and properties of which have heretofore been discussed.

The composition of the radicals ethule and acetule has already been given (908). These, it is true, have never been obtained in a separate state, but they are believed to exist in combination. Now the former, ethule, (C_4H_5) is believed to be the radical of all the ethers both simple and compound. The simple ethers are the oxide, chloride, bromide, sulphuret, &c. of ethule, as sulphuric ether C_4H_5O, and hydrochloric ether C_4H_5Cl; while the compound ethers are properly salts of the oxide of ethule, as hyponitrous ether $C_4H_5O+NO_3$. The compound acids (918) are salts of the oxide of ethule.

1044. Acetule (C_4H_3), is considered the radical of acetic acid. It unites also with various other bodies, forming compounds which are more or less known. Thus, united with 1 at. of oxygen, it forms aldehyde, (from *alcohol dehydratus*), C_4H_3O, with 2 at. of oxygen, it forms aldehydic acid $C_4H_3O_2$, and with 3 at. of oxygen, acetic acid $C_4H_3O_3$.

Olefiant gas (459, 468), the composition of which is C_4H_4, is believed to be a hyduret of this radical, acetule. If this supposition is correct, its true constitution of course is C_4H_3+H.

1045. When this gas and chlorine are brought together (469), chloride of acetule (C_4H_3Cl), and hydrochloric acid (HCl), are at the same time produced, and these immediately combining, form the liquid called *Oil of the Dutch Chemists*, before alluded to. It is properly hydrochlorate of chloride of acetule. By some it has been called *chloric ether*.

OTHER NEUTRAL PRINCIPLES.

1046. Under this head are introduced a number of vegetable principles, which appear to be definite compounds, but do not sustain an intimate relation to any of the preceding substances. Some of them may possess slightly acid or alkaline properties.

1047. *Asparagine.*—This principle is contained in the young shoots of asparagus, in the potato, root of the marsh-mallow, and in the roots of liquorice.

It is obtained by digesting asparagus in cold water for 48 hours, and then straining the liquor and setting it aside to crystalize. It forms regular octohedrons, which are colorless and tasteless, and require 60 parts of cold water for solution. By its decomposition, it yields *aspartic acid.* The composition of asparagine is $NC_4H_4O_3+HO$.

1048. *Bassorin* was first noticed in gum *bassora* by Vauquelin. It is an ingredient of gum tragacanth, and probably occurs in other gums.

Bassorin is characterized by forming with cold water a bulky jelly, which is insoluble in that menstruum, as well as in alcohol and ether.

Boiling water does not dissolve it except by long-continued ebullition, when the bassorin at length disappears, and is converted into a substance similar to gum arabic.

1049. *Caffein* is found in the coffee-berry. It is best prepared by making n aqueous decoction of bruised raw coffee.

Caffein is a white crystaline volatile matter, sparingly soluble in cold water, but very soluble in boiling water and alcohol, and is deposited from these solutions as they cool in the form of silky filaments like amianthus.

It is remarkable for containing a large proportion (29 per cent.) of nitrogen. Its composition is $N_2C_8H_5O_2+HO$. From it is formed *caffeic acid.*

1050. *Cathartin.*—This name has been applied to the active principle of senna. A similar bitter purgative principle, called *Cytisin,* has been prepared from the *cytisus alpinus.*

1051. *Capsicin* is the name given to a volatile pungent substance which is extracted from the *capsicum annuum,* or cayenne pepper.

1052. *Piperin.*—Is the name which is applied to a white crystaline substance extracted from black or white pepper. It is tasteless, and is quite free from pungency, the stimulating property of the pepper being found to reside in a fixed oil.

Its composition is $NC_{34}H_{19}O_6$.

1053. *Phloridzine* is a substance obtained from the bark of the various species of apple, pear, plum, and cherry trees. Its composition in crystals is $C_{21}H_{11}O_8+4HO$.

1054. *Anemonine* is a substance obtained from various species of the anemone.

1055. *Sinapisin.*—A peculiar principle, called *sinapisin,* or *sinapin,* has been extracted from mustard-seed (*sinapis alba*). It is obtained by forming an aqueous decoction of mustard-seed, adding subacetate of oxide of lead as long as a precipitate falls, removing the excess of that acid, and concentrating the filtered solution. The first crop of crystals is purified by a second crystalization.

Pure sinapisin is white and inodorous, has a bitter taste, accompanied with a flavor of mustard, is more soluble in hot water or alcohol than when they are cold, and crystalizes in pearly needles or small prisms arranged in tufts.

1056. *Vegetable Albumen.*—Vegetable albumen, as the name implies, is a vegetable substance much resembling the animal substance called by this name. It is obtained from the seeds of various vegetables, as wheat, peas, beans, &c.

Gluten.—This constitutes the principal nutritious parts of the different kinds of grain, and gives to dough all its tenaciousness.

Olivile is extracted from the gum of the olive tree.

Sarcocol is the concrete juice of a tree found in the northern parts of Africa, called *penæa sarcocolla.*

Rhubarbarin and *Rhein* are extracted from the common rhubarb.

Scillintin is a bitter principle of squills. It is obtained from the *scilla maratima.*

Senegin is a bitter acrid principle contained in the root of the *polygala senega.*

Plumbagin is extracted from the *plumbago Europæa.*

Salicin was discovered in 1830, in *salix helix.* It is found also in the *opulis tremula* and other trees.

Gentianin is procured in acicular crystals from gentian.

Suberin is found in the cellular tissue of the common cork tree.

Columbine is obtained from the columbo root.

Quassine constitutes the bitter principle of the quassia aurora.

Absinthiin is the bitter principle of common wormwood (*artemisia absinthium.*)

SECTION VI.

OLEAGINOUS, RESINOUS, AND BITUMINOUS SUBSTANCES.

OLEAGINOUS SUBSTANCES.

1057. OILS are characterized by their peculiar unctuous feel, by their inflammability, and by being insoluble in water. They are divided into the fixed and the volatile oils, the former being comparatively fixed even at elevated temperatures, and therefore giving a permanent greasy stain to paper, while the latter, owing to their volatility, produce a stain which disappears by a gentle heat.

1058. *Fixed Oils.*—The fixed oils are usually contained in the seeds of plants, as, for example, in the almond, linseed, rape-seed, and poppy-seed; but olive oil is extracted from the pulp which surrounds the stone. They are procured by bruising the seed, and subjecting the pulpy matter to pressure in hempen bags, a gentle heat being generally employed at the same time to render the oil more limpid.

Fixed oils are nearly inodorous, have little taste, and are lighter than water. Some, such as cocoa-nut and palm oil, are fixed at 50° or 60°; but most of them are fluid at common temperatures, and they all become limpid when warm. They are commonly of a yellow color, but may be rendered nearly or quite colorless by the action of animal charcoal.

They are chiefly compounds of the three principles, stearine, oleine, and margarine, in various proportions, united with glycerine (oxide of glycerule), from which respectively stearic, oleic, and margaric acids are prepared by means already described. Oleine is liquid at ordinary temperatures, but stearine and margarine are solid though differing in fusibility.

1059. The fixed oils may be divided into the two classes of *siccative* or *drying oils*, which absorb oxygen and become rancid or even waxy, on exposure to the air, and *fat oils*, which are not so affected.

When the drying oils are spread upon the surface of wood or other substance, and exposed to the air, a thin film or pellicle is formed, which serves to protect it from the further action of the atmosphere or moisture. The various substances called *pigments* or *paints*, as chromate of lead, vermilion, &c., are mixed with this oil in painting, to give the desired color

Litharge, and sometimes other substances, are mixed with the oil to increase its drying properties. They are also found to dry more rapidly by having been previously boiled. The drying oils are used in preparing *printer's ink*, the coloring substance of which is lampblack.

1060. The absorption of oxygen by drying oils, is under some circumstances so abundant and rapid, and accompanied with so much heat, that light porous combustible materials, such as lampblack, hemp, or cotton-wool, may be kindled by it. Substances of this kind, moistened with linseed oil, have been known to take fire during the space of twenty-four hours, a circumstance which has repeatedly been the cause of extensive fires in ware-houses and cotton manufactories.

Fixed oils do not unite with water, but they may be permanently suspended in that fluid by means of mucilage or sugar, so as to constitute an *emulsion*. They are for the most part very sparingly soluble in alcohol and ether.

1061. The action of the alkaline bases and oxide of lead upon the fixed oils has long been known. With ammonia they form a soapy compound called *volatile liniment;* with the alkalies, the well-known substance *soap*; and with oxide of lead, the substance called *diachylon* (749), as before described.

1062. There are three varieties of soap in commerce—*hard white soap, hard yellow soap*, and *soft soap*. They are usually prepared from animal oils because of their cheapness, but may properly be described here.

The first variety, hard white soap, is made from tallow and caustic soda, which are boiled together. Stearate of soda is its principle solid ingredient; but it usually contains from 40 to 60 per cent. of water.

1063. Hard yellow soap is made of soda, tallow, and some coarse oil, and rosin. Generally 2 parts of fatty matter are used, and 1 part of rosin. The fatty matter and the rosin are first dissolved in impure caustic potassa, and then common salt is added. By this process the potassa soap first formed is decomposed, and soda soap produced, at the same time with chloride of potassium.

1064. Soft soap is made by boiling together some fatty matter, and impure caustic potassa, prepared by lixiviating common wood ashes, (439, 600).

The hardness of soap depends chiefly upon the alkali used, soda forming hard soap, and potassa forming the soft.

Soaps made of vegetable oils, are usually mixtures of oleate and margarate of potassa or soda, while those made of animal oils contain the oleate, mixed with the stearate and margarate of these alkalies.

The following are some of the most important of the fixed oils:

1065. *Linseed Oil*, obtained from the seeds of common flax, *linum usitatissimum*.

1066. *Oil of Walnuts*, procured from the common walnut.

1067. *Oil of Hempseed*, from the seed of common hemp, *cannabis sativa*. These three oils are distinguished for their drying properties, and are much used by painters.

1068. *Castor Oil* is obtained from the seeds of the *ricinus communis*. Its use in medicine is well known.

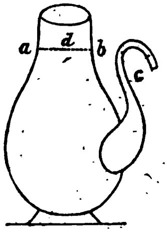
1069. *Olive Oil*, prepared from the common olive, the fruit of the *olea Europæa*.

1070. *Croton Oil*, from the fruit of the *croton tiglium*. It is used in medicine.

There are also other oils, the source of which is generally indicated by the name.

1071. *Volatile or Essential Oils.*—These oils are so named because of their volatility, and from the fact of their alcoholic solutions being usually called *essences*. Aromatic plants owe their peculiar flavor and odor to the presence of these oils, which are obtained from their different parts, as the flowers, the leaves, stem, bark, or roots, by careful distillation, water being put into the still along with the plant, in order to prevent the latter from being burned. The oil and water pass over into the recipient, and the oil collects at the bottom or the surface of the water, according to its density.

Fig. 92.



The Italian recipient, figure 92, (Webster's Chemistry), answers well for collecting these oils. This vessel being filled to the level of *a d b* with water, it will of course pass off at *c*. If now the mixed oil and water are poured into the vessel, the oil being usually lighter than water, will remain in the space *d*, while the water passes off at *c*, as before shown.

1072. Essential oils have a penetrating odor and acrid taste, which are often pleasant when sufficiently diluted. They are soluble in alcohol, though in different proportions. They are sparingly dissolved by water, and hence water acquires the odor of the oil with which it is distilled. With the fixed oils they unite in every proportion, and are sometimes adulterated with them, an imposition easily detected by the mixed oil causing on paper a greasy stain which is not removed by heat.

Some of them do not exist ready formed in the plant, but are produced from substances existing in them, during the process of distillation.

Volatile oils do not unite readily with metallic oxides, and are attacked with difficulty even by the alkalies. The substance called Starkey's soap is made by triturating oil of turpentine with an alkali.

1073. *Oil of Turpentine* is procured by distillation from common turpentine, a substance which exudes from incisions made in the wood of several species of the genus Pinus. It is a limpid colorless liquid, of specific gravity about 0.87, and boils at 315°. It is composed, when pure, solely of carbon and hydrogen ($C_{20}H_{16}$), but absorbs oxygen from the atmosphere, and forms resin.

1074. When a current of hydrochloric acid gas is passed through this substance, a solid compound is formed, which, from its resemblance to camphor, is called *artificial camphor*. Its composition is $C_{20}H_{17}Cl = C_{20}H_{16} + HCl$. From this compound the hydrochloric acid may be separated, and the oil of turpentine ($C_{20}H_{16}$) again obtained. Dumas has given it the name of *camphene*.

1075. There are some six or eight other oils which appear to be isomeric with this, but their equivalents are different, as well as their action upon polarized light.

1076. *Oil of Bitter Almonds* is prepared by distilling with water the bruised almonds. After it is purified from hydrocyanic acid, which is distilled over with it, it is perfectly colorless, and has a strong odor. Its sp. gr. is 1.04, and it boils at 356°. It is a hyduret of the compound radical, benzule, $C_{14}H_5O_2$ (908), which was first obtained from this substance. Oxide of the same radical constitutes benzoic acid, (937).

1077. *Camphor.*—The common camphor of commerce is well known. It is obtained from the trunk and branches of the *laurus camphora* of Japan, by distillation.

It is a solid white substance, of sp. gr. 0.99, and has a pungent odor, and bitter aromatic taste. It melts at 347° and boils at 390°. Its composition is $C_{20}H_{16}O_2$, which shows it to be an oxide of camphene (1074).

Camphor is insoluble in water, but when triturated with sugar or lime and then mixed with that liquid, a portion of it is taken up by it. In alcohol it dissolves freely, forming the common tincture of camphor.

1078. The name camphor is also applied to the solids deposited from the various volatile oils when exposed to great cold. Many of them, especially that from oil of peppermint, much resemble the common camphor of commerce, in color, taste, odor, solubility, &c.

1079. The number of essential oils is great, and their names even cannot be here given.

RESINOUS SUBSTANCES.

1080. *Resins.*—Resins are the inspissated juices of plants, and commonly occur either pure or in combination with an essential oil. They are solid at common temperatures, brittle, inodorous, and insipid. They are non-conductors of electricity, and when rubbed become negatively electric. They are generally of a yellow color, and semi-transparent.

Resins are dissolved by alcohol, ether, and the essential oils, and the alcoholic and ethereal solutions are precipitated by water, a fluid in which they are quite insoluble. Their best solvent is pure potassa and soda, and they are also soluble in the alkaline carbonates by the aid of heat. The product is in each case a soapy compound, which is decomposed by an acid.

The uses of resin are various. Melted with wax and oil, resins constitute ointment and plasters. Combined with oil or alcohol, they form different kinds of oil and spirit varnish. Sealing-wax is composed of lac, Venice turpentine, and common rosin. The composition is colored black by means of lampblack, or red by cinnabar or red lead. Lampblack is the soot of imperfectly burned resin.

1081. Of the different resins the most important are the common resin or rosin, copal, lac, sandarach, mastich, elemi, and dragon's blood. The first is procured by heating turpentine, which consists of oil of turpentine and resin, so as to expel the volatile oil. The common turpentine, obtained by incisions made in the trunk of the Scotch fir-tree, (*pinus sylvestris*), is employed for this purpose; but the other kinds of turpentine, such as Venice turpentine, that from the larch, (*pinus larix*), Canadian turpentine, from the *pinus balsamea*, or the Strasburgh turpentine, from the *pinus picea*, yield resin by a similar treatment.

When turpentine is extracted from the wood of the fir-tree by heat, partial decomposition ensues, and a dark substance, consisting of resin, empyreumatic oil, and acetic acid, is the product. This constitutes tar, and when inspissated by boiling, it forms *pitch*.

1082. *Amber*.—This is a fossil found abundantly on the southern coast of the Baltic sea, and to some extent on the Yorkshire coast, England, and in some parts of the United States. It occurs sometimes in beds of bituminous wood, and at others on the shore, being doubtless washed out from strata of brown coal by the action of water. Its vegetable origin is amply attested by the substances with which it is associated, by its resinous nature, and by the vegetable matters which it frequently envelopes. It may be regarded as a mixture of several substances, as succinic acid, &c., which may be separated from each other by the proper means.

1083. *Balsams.*—The balsams are semi-fluid resins containing a volatile oil, which may generally be separated by careful distillation, leaving the solid resin. *Balsam of Peru* and *balsam of Tolu* are well known from their use in medicine.

1084. *Gum-resins.*—The substances to which this name is applied are the concrete juices of certain plants, and consist of resin, essential oil, gum, and extractive vegetable matter. The two former principles are soluble in alcohol, and the two latter in water. Their proper solvent, therefore, is proof spirit. Under the class of gum-resins are comprehended several valuable medicines, such as aloes, ammoniacum, assafœtida, euphorbium, galbanum, gamboge, myrrh, scammony, and guaiacum.

1085. *Caoutchouc*, commonly called elastic gum or India rubber, is the concrete juice of the *Hævea caoutchouc* and *Iatropa elastica*, natives of

South America, and of the *Ficus Indica* and *Artocarpus integrifolia*, which grow in the East Indies. It is a soft yielding solid, of a whitish color when not blackened by smoke, possesses considerable tenacity, and is particularly remarkable for its elasticity. It is inflammable, and burns with a bright flame. It is insoluble in water and alcohol; but it dissolves, though with some difficulty, in pure ether. It is very sparingly dissolved by the alkalies, but its elasticity is destroyed by their action.

Caoutchouc is soluble in the essential oils, ether, naphtha, cajeput oil, and in the volatile liquid obtained by distilling caoutchouc; and from all these solvents, except the essential oils, it is left on evaporation without loss of its elasticity. Before actually dissolving, the caoutchouc swells up remarkably, and acquires a soft gelatinous aspect and consistency; in this state it is used for rendering cloth and leather impervious to water, and may be cut with a wet knife into thin sheets or bottles, and be extended to great size, but not without much care.

1086. *Wax.*—This substance, which partakes of the nature of a fixed oil, is an abundant vegetable production, entering into the composition of the pollen of flowers, covering the envelope of the plum and other fruit, especially the berries of the *Myrica cerifera.*

Whether bees-wax is to be considered as a vegetable production collected by the bees, or whether it is manufactured by them, seems not to be determined. It is found to consist of two distinct principles, one of which, called *cerine*, is soluble in boiling alcohol, while the other, called *myricine*, is insoluble.

1087. Common wax is always more or less colored, and has a distinct peculiar odor, of both which it may be deprived by exposure in thin slices to light, air, and moisture, or more speedily by the action of chlorine. At ordinary temperatures it is solid, and somewhat brittle; but it may easily be cut with a knife, and the fresh surface presents a characteristic appearance, to which the name of waxy lustre is applied. Its specific gravity is 0.96. As it burns with a clear white light it is employed for forming candles.

BITUMINOUS SUBSTANCES.

1088. Under this head a considerable variety of substances is included, some of which are obtained by the distillation of vegetable matter; but others, though of vegetable origin, are found in the earth, or issue from its surface.

1089. *Naphtha.*—Naphtha is a liquid which exudes from the earth in some parts of Italy, and in Persia. It is an ingredient of the dark bituminous liquid called petroleum, and may be obtained from it by distillation. Coal-tar yields by distillation a liquid very similar to mineral naphtha, and to all appearance identical with it.

Naphtha is generally of a yellowish color, but may be rendered perfectly limpid by distillation; it possesses a strong peculiar odor, by which it may always be recognised. Its sp. gr. when highly rectified, is 0,753 at 61°. In a platinum vessel it begins to boil at 150°, but the thermometer is not stationary until it reaches 192°. It retains its liquid form at 0°.

1090. *Petroleum* is much less limpid than naphtha, has a reddish-brown color, and is unctuous to the touch. It is found in several parts of Britain and the continent of Europe, in the West Indies, and in different parts of the United States. It occurs particularly in coal districts. *Mineral tar* is very similar to petroleum, but is more viscid and of a deeper color. Both these species become thick by exposure to the atmosphere, and pass into solid bitumen.

1091. *Asphaltum* is a solid, brittle bitumen, of a black color, vitreous lustre, and conchoidal fracture. It melts easily, and is very inflammable. It emits a bituminous odor when rubbed, and by distillation yields a fluid like naphtha. It is soluble in about five times its weight of naphtha, and the solution forms a good varnish. It is rather denser than water.

Asphaltum is found on the surface and on the banks of the Dead Sea, and occurs in large quantity in Barbadoes and Trinidad. It was employed by the ancients in building, and is said to have been used by the Egyptians in embalming.

1092. *Creosote.*—This substance exists in solution in crude pyroligneous acid; but it is best prepared from those portions of the oil distilled from wood-tar, which are heavier than water. The oil is first freed from adhering acetic acid by carbonate of potassa, and after separation from the acetate, is distilled.

To insure purity, it must be several times re-distilled, care being taken to neutralize any free acid.

Creosote is a colorless, transparent liquid of an oily consistence, which retains its fluidity at —17°, has a sp. gr. of 1.04 at 68°, boils at 397°, is a non-conductor of electricity, and refracts light powerfully. It has a burning taste followed by sweetness, and its odor is like that of wood-smoke, or rather of smoked meat. It is highly antiseptic to meat: the antiseptic virtue of tar, smoke, and crude pyroligneous acid, seems owing to the presence of creosote. Its name, (from κρεας, *flesh*, and σωζω, *I save*), was suggested by this property.

Creosote requires about 80 parts of water for solution, and is soluble in every proportion in alcohol, ether, sulphuret of carbon, eupione, and naphtha. It has neither an acid nor alkaline reaction with test paper, but combines both with acids and alkalies.

This substance is used considerably in medicine, both internally and externally, and is often found to be very efficacious.

Picamar, *capnomar*, *paraffine*, *eupione* and *pittacal*, are substances somewhat analogous to creosote, and are obtained by the destructive distillation of various vegetable substances.

1093. *Coal.*—The numerous varieties of mineral coal known in commerce may be reduced to two, *bituminous coal*, and *stone coal*, or *anthracite*.

Bituminous coal is distinguished by its softening like wax when thrown upon burning coals, and giving off much gas when heated, which of course burns with flame. It is also much lighter than anthracite, and more easily ignited.

Some of the different varieties of bituminous coal are *caking*, *splint*, *cherry*, and *cannel* coal. *Jet* also, which is used in jewelry, is a bituminous coal; and in the same family may be included *wood* or *Bovey* coal, sometimes called *lignite*.

When the volatile matter is expelled from the different varieties of bituminous coal, the hard, inodorous carbon which remains is called *coke*, (439).

1094. *Anthracite.*—Anthracite or glance coal differs from common coal, which it frequently accompanies, in containing no bituminous substances, and in not yielding inflammable gases by distillation. Its sole combustible ingredient is carbon, and consequently it burns without flame.

It often occurs in the immediate vicinity of basalt, under circumstances which lead to the suspicion that it is coal from which the volatile ingredients have been expelled by subterranean heat.

Anthracite is found in different countries, but nowhere in such profuse abundance as in the eastern part of the State of Pennsylvania, which supplies most of the northern and eastern parts of the United States with fuel.

1095. *Illuminating Gas.*—The gas used so extensively at the present day, for illuminating the streets of cities, is prepared by the distillation of oleaginous and resinous substances, and bituminous coal. In the United States common rosin is much used, but in other countries bituminous coal, or coarse oil of some kind, is found to be cheaper. The gas formed by the different processes, is probably a mixture of several compounds of carbon and hydrogen, but the most important is supposed to be olefiant gas, previously described, (468).

1096. The formation of coal and oil gas is a process of considerable delicacy. Coal gas is prepared by heating coal to redness in iron retorts. The quality of the gas, as made at different places, or at the same place at different times, is very variable; the specific gravity of some specimens having been found as low as 0.42, and that of others as high as 0.700. These differences arise in part from the nature of the coal, and partly from the mode in which the process is conducted. The regulation of the degree of heat is the chief circumstance in the mode of operating, by which the quality of the gas is affected.

An illuminating gas like that formed by the distillation of coal, is sometimes presented ready formed by nature, and constantly issues into the air like light carburetted hydrogen, from between beds of coal in a coal mine. The illuminating power is not equal to that of the gas formed by art, but, by means of suitable apparatus, the gas is sometimes collected as it issues from the earth, and whole villages lighted by it. The village of Fredonia in the western part of New York is lighted in this manner.

1097. Oil gas requires still more care in its preparation than that made from coal. To form it of the proper density the retort should be kept at a dull red heat, and the oil allowed to enter a little at a time. When rosin is used, it is melted before it is introduced into the retort.

Gas formed from coal has always to be cleansed from hydrosulphuric acid, by passing it through milk of lime, before it is fit for use; and even then it is often found to yield some sulphurous acid during its combustion. Oil gas, or that formed from rosin, on the contrary, needs no purification.

SECTION VII.

COLORING MATTERS.

1098. INFINITE diversity exists in the color of vegetable substances; but the prevailing tints are red, yellow, blue, and green, or mixtures of these colors. Coloring matter rarely or never occurs in an insulated state, but is always attached to some other proximate principle, such as mucilaginous, extractive, farinaceous, or resinous substances, by which some of its properties, and particularly that of solubility, is greatly influenced.

Several of the metallic oxides, and especially alumina and the oxides of iron and tin, form with coloring matter insoluble compounds, to which the name of *lakes* is applied. Lakes are commonly obtained by mixing alum or pure chloride of tin with a colored solution, and then by means of an alkali precipitating the oxide, which unites with the color at the moment of separation. On this property are founded many of the processes in dyeing and calico printing. The art of the dyer consists in giving a uniform and permanent color to cloth. This is sometimes effected merely by immersing the cloth in the colored solution; whereas in other instances the affinity between the color and the fibre of the cloth is so slight that it only receives a stain which is removed by washing with water. In this case some third substance is requisite, which has an affinity both for the cloth and coloring matter, and which, by combining at the same time with each, may cause the dye to be permanent. A substance of this kind was formerly called a *mordant*; but the term *basis* is now more generally employed. The most important bases, and indeed the only ones in common use, are alumina, oxide of iron, and oxide of tin. The two former are exhibited in combination either with the sulphuric or acetic acid, and the latter most commonly as the chloride. Those coloring substances that adhere to the cloth without a basis are called *substantive* colors, and those which require a basis, *adjective* colors.

Various as are the tints observable in dyed stuffs, they may all be produced by the four simple ones, blue, red, yellow, and black; and hence it will be convenient to treat of coloring matters in that order.

1099. *Blue Dyes.*—Indigo is chiefly obtained from an American and Asiatic plant, the *Indigofera*, several species of which are cultivated for the purpose. It is likewise extracted from the *Nerium tinctorium*; and an inferior sort is prepared from the *Isatis tinctoria* or *woad*, a native of Europe.

The indigo of commerce, which occurs in cakes of a deep blue color and earthy aspect, is a mixture of several substances, as indigo-brown, indigo-red, and indigo-blue, each of which may be obtained in a separate state. These may be converted into each other by a slight change of composition.

Indigo-blue is the well known coloring substance of common indigo. When pure, its composition is $NC_{16}H_5O_2$. At a high temperature it sublimes, and condenses into long flat acicular crystals, which appear red by reflected, and blue by transmitted light. It has neither taste nor odor, and it is insoluble in water, alkalies, and ether. Boiling alcohol takes up a trace of it, and acquires a blue tint; but it is generally deposited again on standing. Concentrated sulphuric acid, especially that of Nordhausen, dissolves it readily, forming an intensely deep blue solution, commonly termed *sulphate of indigo*, which is employed by dyers for giving the *Saxon blue*.

1100. *Red Dyes.*—The substances chiefly employed for producing red dyes are *cochineal*, an insect which feeds upon several species of the cactus; *archil*, which is obtained from a peculiar kind of lichen (*lichen rocella*), growing in the Canary islands; *Brazil wood*, *madder*, *logwood*, and *safflower*. The coloring principle of logwood has been obtained in a separate state, and called *hematin*. Madder is prepared from the root of the *Rubia tinctorum*, and safflower is simply the flower of the *carthamus tinctorius*.

Litmus or *turnsol* is a different preparation from the same plant as archil, the lichen rocella; and *carmine* is prepared from cochineal.

1101. *Yellow Dyes.*—The chief yellow dyes are quercitron bark, turmeric, wild American hickory, fustic, and saffron; all of which are adjective colors. Quercitron bark, which is one of the most important of the yellow dyes, was introduced into notice by Bancroft.

Turmeric is the root of the *curcuma longa*, a native of the East Indies. Paper stained with a decoction of this substance, constitutes the *turmeric* or *curcuma* paper employed by chemists as a test of free alkali, by the action of which it receives a brown stain.

1102. *Black Dyes.*—The black dye is made of the same ingredients as writing ink, and, therefore, consists essentially of a compound of oxide of iron with gallic acid and tannin. From the addition of logwood and acetate of copper, the black receives a shade of blue.

By the dexterous combination of the four leading colors, blue, red, yellow and black, all the other shades of color may be procured. Thus green is communicated by forming a blue ground with indigo, and then adding a yellow by means of quercitron bark.

1103. *Chlorophyle.*—This name has been applied by Pelletier and Caventou to the green coloring matter of leaves. It is prepared by bruising green leaves into a pulp with water, pressing out all the liquid, and boiling the pulp in alcohol. The solution is mixed with water, and the spirit driven off by distillation, when the chlorophyle is left floating on the surface of the water. As thus obtained, it appears to be wax stained with the green color of the leaves; and from some late observations the wax may be removed by ether, and the coloring matter left in a pure state. The red autumnal tint of the leaves, according to the same observer, is the effect of an acid generated in the leaf. The green tint may be restored by the action of an alkali.

SECTION VIII.

CHEMICAL PHENOMENA OF VEGETATION.

1104. Germination is the process by which, a new plant originates from seed. A seed consists essentially of two parts, the *germ* of the future plant, endowed with a principle of vitality, and the *cotyledons* or *seed-lobes*, both of which are enveloped in a common covering of cuticle. In the germ two parts, the *radicle* and *plumula*, may be distinguished, the former of which is destined to descend into the earth and constitute the root, the latter to rise into the air and form the stem of the plant. The office of the seed-lobes is to afford nourishment to the young plant, until its organization is so far advanced, that it may draw materials for its growth from extraneous sources. For this reason seeds are composed of highly nutritious ingredients. The chief constituent of most of them is starch, in addition to which they frequently contain gluten, gum, vegetable albumen or curd, and sugar.

1105. The conditions necessary to germination are threefold; namely, moisture, a certain temperature, and the presence of oxygen gas. The necessity of moisture to this process has been proved by extensive observation. It is well known that the concurrence of other conditions cannot enable seeds to germinate provided they are kept quite dry.

A certain degree of warmth is not less essential than moisture. Germination cannot take place at 32°; and a strong heat, such as that of boiling water, prevents it altogether, by depriving the germ of the vital principle. The most favorable temperature ranges from 60° to 80°, the precise degree varying with the nature of the plant, a circumstance that accounts for the difference in the season of the year at which different seeds begin to germinate.

1106. The various chemical changes that take place in the germination of seeds, are seen in the process of malting, which has been already described, (1021). A kind of saccharine fermentation is produced, by which nutriment is supplied for the young plant during the early stages of its growth. This seems to be occasioned by the influence of the active principle *diastase*, (1008), which is not pre-existent in the seed, but is formed by the action of the air and moisture on the albumen contained in it. When the process of germination is over, the plant is found provided with the necessary organs for procuring its nutriment from the atmosphere and soil; and there remains of the seed only its ligneous husk, which sometimes perishes in the ground, but at others rises to the surface and performs for a time the functions of leaves.

1107. *Growth of Plants.—Assimilation of Carbon.*—We have already noticed (410), the beautiful provision, by which the two great classes of organized bodies mutually compensate for the change each produces in the constituents of the atmosphere, and continue that proportion of them which is conducive to the healthful existence of both. Animals during respiration are constantly giving off carbonic acid, while plants by the action of light absorb carbonic acid and give off oxygen.

1108. The carbon thus obtained by plants, and the water which is absorbed both by the roots and leaves, furnish the elements for woody matter, and other bodies, as sugar, starch, &c., which contain oxygen and hydrogen in the proper proportion to form water. But a much more complex action than this would imply, usually takes place. The absorption of carbonic acid and liberation of oxygen goes on only in the light: in the dark an opposite effect is produced, oxygen is absorbed and carbonic acid is given off; and the same effect is constantly produced by the colored portions, as the flowers and fruit. But it has been fully proved that, on the whole, the quantity of carbonic acid absorbed is much greater than that evolved, whilst the quantity of oxygen evolved is much greater than that absorbed. The probability therefore is, that much or all of the carbon in plants is imparted to them through the medium of the atmosphere; while the supply of oxygen in the air, in place of that which is constantly disappearing in combustion and respiration, is kept up by that which plants are ever giving off.

1109. Now in the softer parts of various plants, abundance of starch is often found (997); and in the tubes and cells of ordinary wood it also occurs, in a state indicating a change into lignine or woody fibre. For the formation of starch, $C_{12}H_{10}O_{10}$, water and carbon only are required; and this is supposed to be the actual result of the respiratory process of the plant. By giving off 2 eq. of water it becomes *lignine* or woody fibre, $C_{12}H_8O_8$. By a process which cannot yet be explained, this same substance, starch, is probably also converted into gum and sugar, though we cannot produce the change in the laboratory.

1110. The other numerous secondary products, as the vegetable acids, oils, coloring matters, &c., which characterize plants, may be formed from starch during the inverse respiratory action just alluded to, (1108), in which carbonic acid is given off, and oxygen absorbed from the atmosphere. During the day the assimilating power of the plant is in action, and carbonic acid is rapidly absorbed, and oxygen evolved; but during the night, while the plant is in repose, this nutritious action ceases, and a different process commences during which the various substances natural to the plant are elaborated, attended by the absorption of oxygen from the atmosphere, and the evolution of carbonic acid and water. This change is well illustrated by certain plants, as the *Cacalia ficoides*, the leaves of which are bitter in the evening, but in the morning are sour like those of sorrel. During the night oxygen has been absorbed, and an acid generated from materials that were combined, the evening previous, in a different mode.

The important changes that occur during the ripening of fruits, probably consist merely in new arrangements of the particles composing the substances found in these fruits.

1111. *Assimilation of Nitrogen.*—Though the chief constituents of plants are oxygen, hydrogen and carbon (943), yet nitrogen serves a most important purpose, not only as an element of many active vegetable products, as the vegetable alkalies, but also as a constituent of those vegeto-animal substances, as gluten, albumen, legumine, &c., which are found in all parts of the plant dissolved in its juices, and are the principal agents in producing the transformations necessary for their germination and growth. The conversion of starch into sugar, of starch into woody fibre, and the vast variety of other products found in plants, the ripening of fruit, &c., all have their origin in a series of actions, induced and maintained by the active fermentation of their nitrogenized materials. In vegetable substances used for food, this nutritive power is found proportioned to the quantity of nitrogen they contain.

Most of the nitrogen, as well as the carbon, of plants, is probably obtained from the atmosphere, which always contains a quantity of ammonia, derived from the putrefaction of organic matter. This is absorbed by them, and the nitrogen passes into their constitution. Some plants derive nitrogen from the atmosphere with much greater facility than others. Wheat, though it contains much nitrogen, is scarcely capable of absorbing it from the air, but derives it from the organic matter of the soil; while trefoil thrives nearly as well when planted in pure sand, and supplied with water, as when sown in ordinary soil. Its nourishment, therefore, of which nitrogen is an important part, is derived chiefly from the atmosphere.

1112. *Inorganic Constituents of Plants.*—Besides the substances which form the matter of plants, various inorganic bodies, as the salts, are usually found contained in them, and seem to serve some important purpose. If a plant is made to vegetate in a soil containing in it small quantities of several salts, we find that while it continues in health, it seems to exercise a remarkable discretionary power, absorbing some, and rejecting others. Those absorbed most freely are such as are required for its proper growth, and are not given up to the water in which the plant may be immersed; while some are absorbed and again given off, and others still are entirely rejected, as being injurious. Most plants, as has already been remarked, contain a small quantity of some salt of potassa, which exists as a carbonate in the ashes resulting from their combustion; but plants that grow near the sea, or springs of salt water, usually contain soda instead of potassa. Silica, lime, magnesia, &c., are also often contained in plants.

1113. As these inorganic substances are necessary for the proper growth of plants, and all plants do not require the same substance, the reason is plain why the cultivation of certain crops is found so much more successful in some soils than in others. Thus wheat, which contains silica, lime, magnesia, potassa, and phosphoric acid, could not be expected to flourish in a soil destitute of potassa and phosphoric acid. We see too, why bone-dust and wood-ashes, containing as they do the substances wanting in the soil for the production of this crop, should be found greatly to promote its growth, and become, under the circumstances, powerful fertilizers.

1114. *Nature and Use of Manures.*—The object and use of manures have already been in part anticipated by the remarks above. Every substance is called a manure which, applied to a soil, increases its productiveness. In a particular case it may be a substance which is required in the proposed crop, but of which the soil is deficient; or it may be a substance designed merely to give the soil a proper texture, so that it may more easily be penetrated by the rootlets of the plants, or to increase its adhesiveness to enable it to retain longer the moisture that falls upon it. It is in the manner last mentioned, probably, that most mineral manures, as lime, marl, &c., usually operate.

1115. From the preceding remarks, the great advantage of *rotation of crops* may readily be seen. The mineral constituents of a soil are derived from the disintegration of its subjacent rocks; and some of them being contained only in small quantities, by continued succession of the same crop may be entirely removed, and the soil become impoverished. By substituting another crop, which requires little or none of the material which has been exhausted, an abundant harvest may be obtained; and the soil, by the gradual decomposition of its subsoil, recover its former constitution. Indeed, a succession of crops may be so arranged, that, instead of impoverishing a soil, it will be gradually enriched, by the additions made to its organic components by the roots and rejected parts of the various crops left upon it.

1116. The great value of organic manures is supposed to depend almost entirely upon the nitrogen they supply to the soil. The most of the nitrogen in plants is contained in the seed, tubers, &c., those parts which are selected by man for food, or for medicinal purposes, in consequence of the active principles they contain; and but little is found in the stem, leaves, root, &c., which are rejected as useless. The residue of a former season, therefore, may manure the land abundantly, so far as carbon is concerned, but there will be a deficiency of nitrogen, an essential element of the future desired crop—an element, too, which many plants, and especially the different varieties of grain, are incapable of assimilating directly from the atmosphere (1111). This deficiency is supplied by the decaying animal and vegetable substances used as manures; the value of which will therefore be very nearly in proportion to the nitrogen they supply. If mere ammoniacal salts are used, or perishable animal substances, their whole benefit is imparted to the crop immediately succeeding their application; but organic substances which decay but slowly, yield a more permanent benefit: their nitrogen is gradually evolved, and though little benefit at first appears, the soil is at length found to be essentially improved.

1117. In healthy vegetation, light serves a most important purpose; indeed, without it, no plant could come to perfection. The peculiar action of plants during the day, by which carbonic acid is absorbed and oxygen evolved (1108), is dependent upon this principle; and the reverse action in the night is because of its absence. A plant which grows in darkness, as in a cellar, however rich may be the soil in which it stands, remains soft, its color pale, and its woody fibre unformed. When brought to the light, it perhaps increases in volume less rapidly, but the healthy action of the organs at once commences; the green color appears, and all the parts of the plant begin gradually to advance to maturity.

CHAPTER III.

ANIMAL CHEMISTRY.

1118. We include in this chapter most substances of animal origin, but some of this class being produced also in vegetables, have already been described in Vegetable Chemistry (900). The essential constituents of animal compounds are oxygen, hydrogen, carbon, and nitrogen; but some also contain phosphorus, sulphur, iron, and earthy and saline matters in small quantity;—a few contain no nitrogen.

1119. Animal substances, in general, are less permanent than those of vegetable origin; and when life is extinct, they at once undergo the spontaneous change called *putrefaction*, during which their elements resolve themselves into new and often very complex modes of combination. Animal substances cannot always be easily distinguished from those of vegetable origin; but usually the former may be known by the peculiar and offensive odor given off by them during their combustion.

SECTION I.

COMPOSITION OF THE ANIMAL TISSUES.

1120. *Fibrin.*—Fibrin enters largely into the composition of the blood, and is the basis of the muscles; it may be regarded, therefore, as one of the most abundant of the animal principles. It is most conveniently procured by stirring recently drawn blood with a stick during its coagulation, and then washing the adhering fibres with water until they are perfectly white. It may also be obtained from lean beef cut into small slices, the soluble parts being removed by digestion in several successive portions of water.

1121. Fibrin is solid, white, insipid, and inodorous. When moist it is somewhat elastic, but on drying, it becomes hard, brittle, and semi-transparent. In a moist, warm situation it readily putrefies. It is insoluble in water at common temperatures, but is dissolved in very minute quantity by the continued action of boiling water. It is insoluble also in alcohol and ether.

Fibrin is dissolved by pure potassa, and is thrown down when the solution is neutralized. The fibrin thus precipitated, however, is partially changed, since it is no longer soluble in acetic acid. It is soluble likewise in ammonia.

The composition of fibrin, according to Kane, is expressed by the following formula, $C_{300}H_{620}N_{100}O_{240}+PS_2$.

1122. *Albumen.*—Albumen enters largely into the composition both of animal fluids and solids. Dissolved in water, it forms an essential constituent of the serum of the blood, the liquor of the serous cavities, and the fluid of dropsy; and in a solid state it is contained in several of the textures of the body, such as the cellular membrane, the skin, glands, and vessels. From this it appears that albumen exists under two forms, liquid and solid.

It is also found in vegetables, (1056), and is then called *vegetable albumen*, which however appears to be in composition precisely the same as that obtained from animals.

Liquid albumen is best procured from the white of eggs, which consists almost solely of this principle, united with water and free soda, and mixed with a small quantity of saline matter. In this state it is a thick glairy fluid, insipid, inodorous, and easily miscible with cold water, in a sufficient quantity of which it is completely dissolved. When exposed in thin layers to a current of air, it dries, and becomes a solid transparent substance, which retains its solubility in water, and may be preserved for any length of time without change; but if kept in its fluid condition, it readily putrefies. From the free soda which they contain, albuminous liquids have always an alkaline reaction.

1123. Liquid albumen is coagulated by heat, alcohol, and the stronger acids. Undiluted albumen is coagulated by a temperature of 160°, and when diluted with water at 212°. Water which contains only 1.1000th of its weight of albumen is rendered opaque by boiling. On this property is founded the method of clarifying by means of albuminous solutions; for the albumen being coagulated by heat, entangles in its substance all the foreign particles which are not actually dissolved, and carries them with it to the surface of the liquid. The character of being coagulated by hot water distinguishes albumen from all other animal fluids.

1124. Albumen is precipitated by several reagents, especially by metallic salts. Of these the most delicate as a test is corrosive sublimate, which causes a milkiness when the albumen is diluted with 2000 parts of water. Other metallic solutions, especially solution of ferrocyanide of iron, produce a similar effect.

Albumen coagulates without appearing to undergo any change of composition, but it is quite insoluble in water, and is less liable to putrefy than in its liquid state. It is dissolved by alkalies with disengagement of ammonia, and is precipitated from its solution by acids.

1125. Kane gives the following formula for albumen, $C_{800}H_{620}N_{100}O_{240}+PS_4$ (897), by which it will be seen that it differs in composition from fibrin only in containing 2 additional equivalents of sulphur.

It has been suggested that fibrin and albumen are compounds of *proteine*, a compound radical, the composition of which is expressed by the formula $C_{40}H_{31}N_5O_{12}$. If we let Prt be the symbol for this radical, the formula for fibrin then will become $Prt_{20}+PS_2$, that of albumen $Prt_{20}+PS_4$.

1126. *Gelatin.*—Gelatin exists abundantly in many of the solid parts of the body, especially in the skin, cartilages, tendons, membranes, and bones.

Gelatin is distinguished from all animal principles by its ready solubility in boiling water, and by the solution forming a bulky, semi-transparent, tremulous jelly as it cools. Its tendency to gelatinize is such, that one part of gelatin, dissolved in 100 parts of water, becomes solid in cooling. This jelly is a hydrate of gelatin, and contains so much water that it readily liquefies when warmed. On expelling the water by a gentle heat, a brittle mass is left, which retains its solubility in hot water, and may be preserved for any length of time without change. Jelly, on the contrary, soon becomes acid by keeping, and then putrefies.

1127. The common gelatin of commerce is the well-known cement called *glue*, which is prepared by boiling cuttings of parchment, or the skins, ears, and hoofs of animals, and evaporating the solution: it may also be prepared from bones. Isinglass, which is the purest variety of gelatin, is prepared from the sounds of fish of the genus *acipenser*, especially from the sturgeon. The animal jelly of the confectioners is made from the feet of calves, the tendinous and ligamentous parts of which yield a large quantity of gelatin.

Gelatin is insoluble in alcohol, but is dissolved readily by most of the diluted acids, which form an excellent solvent for it.

1128. Gelatin manifests little tendency to unite with metallic oxides. Corrosive sublimate and acetate of oxide of lead do not occasion any precipitate in a solution of gelatin, and the salts of tin and silver affect it very slightly. The best precipitant for it is tannic acid. By means of an infusion of gallnuts, Bostock detected the presence of gelatin when mixed with 5000 times its weight of water; and its quantity may even be estimated approximately by this reagent. But, since other animal substances, as for example albumen, are precipitated by tannic acid, it cannot be relied on as a test of gelatin. The best character for this substance is that of solubility in hot water, and of forming a jelly as it cools.

The composition of gelatin is expressed by the following formula: $C_{13}H_{10}N_2O_5$.

1129. *Bones.*—The bones of animals consist of earthy salts, chiefly phosphate of lime (503), and animal matter intimately blended, the former of which are designed for giving solidity and hardness, and the latter for agglutinating the earthy particles. The animal substances are chiefly cartilage, gelatin, and a peculiar fatty matter called marrow. On reducing bones to powder, and digesting them in water, the fat rises and swims upon its surface, while the gelatin is dissolved. By digesting bones in dilute hydrochloric acid, the earthy salts are dissolved, and a flexible mass remains which retains the original figure of the bone, and consists of gelatin and cartilage: the former is by far the most abundant, since nearly the whole may be dissolved in boiling water, and yields a solution possessed of all the properties of gelatin. The animal matter of bones is formed before the earthy matter, and constitutes the nidus in which the latter is deposited.

1130. When bones are heated in close vessels, a large quantity of carbonate of ammonia, some fetid empyreumatic oil, and the usual inflammable gases, pass over into the recipient; while a mixture of charcoal and earthy matter, called animal charcoal, remains in the retort. If, on the contrary, they are heated to redness in an open fire, the charcoal is consumed, and a pure white friable earth is the sole residue.

According to the analysis of Berzelius, 100 parts of dry human bones consist of animal matters 33.3, phosphate of lime 51.04, carbonate of lime 11.3, fluoride of calcium 2, phosphate of magnesia 1.16, and soda, chloride of sodium, and water, 1.2.

1131. *Teeth* are composed of the same materials as bone; but the enamel dissolves completely in dilute nitric acid, and, therefore, is free from cartilage. From the analysis of Pepys, the enamel contains 78 per cent. of phosphate and 6 of carbonate of lime, the residue being probably gelatin. The composition of ivory is similar to that of the bony matter of teeth in general.

The shells of eggs and the covering of crustaceous animals, such as lobsters, crabs, and the star-fish, consist of carbonate and a little phosphate of lime and animal matter. The shells of oysters, muscles, and other molluscous animals, consist almost entirely of carbonate of lime and animal matter, and the composition of pearl and mother of pearl is similar.

1132. *Horn* differs from bone in containing only a trace of earth. It consists chiefly of gelatin and a cartilaginous substance like coagulated albumen. The composition of the nails and hoofs of animals is similar to that of horn; and the cuticle belongs to the same class of substances.

1133. *Tendons* appear to be composed almost entirely of gelatin; for they are soluble in boiling water, and the solution yields an abundant jelly on cooling. The composition of the true skin is nearly the same as that of tendons. Membranes and ligaments are composed chiefly of gelatin, but they also contain some substance which is insoluble in water, and is similar to coagulated albumen.

1134. According to the analysis of Vauquelin, the principal ingredient of hair is a peculiar animal substance, insoluble in water at 212°, but which may be dissolved in that liquid by means of Papin's digester, and is soluble in a solution of potassa. Besides this substance, hair contains oil, sulphur, silica, iron, manganese, and carbonate and phosphate of lime. The color of the hair depends on that of its oil; and the effect of metallic solutions, such as nitrate of oxide of silver, in staining the hair, is owing to the presence of sulphur.

The composition of wool and feathers appears analogous to that of hair. The quill part of the feather was found by Hatchett to consist of coagulated albumen.

1135. The flesh of animals, or *muscle*, consists essentially of fibrin; but independently of this principle it contains several other ingredients, such as albumen, gelatin, a peculiar extractive matter called *osmazome*, fat, and salts, substances which are chiefly derived from the blood, vessels, and cellular membrane, dispersed through the muscles. On macerating flesh cut into small fragments, in successive portions of cold water, the albumen, osmazome, and salts are dissolved; and on boiling the solution, the albumen is coagulated. From the remaining liquid the osmazome may be obtained in a separate state by evaporating to the consistence of an extract, and treating it with cold alcohol. By the action of boiling water, the gelatin of the muscle is dissolved, the fat melts and rises to the surface of the water, and pure fibrin remains.

1136. The characteristic odor and taste of soup are owing to the osmazome. This substance is of a yellowish-brown color, and is distinguished from the other animal principles by solubility in water and alcohol, whether cold or at a boiling temperature, and by not forming a jelly when its solution is concentrated by evaporation. Like gelatin and albumen, it yields a precipitate with infusion of gall-nuts.

1137. The substance of the brain, nerves, and spinal marrow differs from that of all other animal textures. The most exact analyses of the brain that we possess, are those of Lassaigne. The different colored portions differ essentially in their nature, but are composed chiefly of water, albumen, a fatty matter, and traces of phosphates and other salts.

The presence of albumen accounts for the partial solubility of the brain in cold water, and for the solution being coagulated by heat, acids, alcohol, and by the metallic salts which coagulate other albuminous fluids. By acting upon cerebral matter with boiling alcohol, the fatty principles and osmazome are dissolved, and the solution in cooling deposites the white fatty matter in the form of crystaline plates. On expelling the alcohol by evaporation, and treating the residue with cold alcohol, the osmazome is taken up, and a fixed oil remains of a reddish-brown color, and an odor like that of the brain itself, though much stronger. These two species of fat differ little from each other, and both yield phosphoric acid when deflagrated with nitre.

1138. *Animal Oils and Fats.*—The fatty principles derived from the bodies of animals are very analogous in composition and properties to the vegetable fixed oils, (1058); and where the latter are comparatively expensive, the former are employed, both for the purpose of giving light, and for the manufacture of soap. Their ultimate elements are carbon, hydrogen, and oxygen; and most of them, like the vegetable fixed oils, consist of two or more definite compounds, such as stearine, margarine, oleine, &c., in a state of combination. From these the stearic, oleic, margaric, &c. acids are formed, which have already been described, (952).

1139. *Train Oil.*—Train oil is obtained by means of heat from the blubber of the whale, and is employed extensively in making oil gas, and for burning in common lamps. It is generally of a reddish or yellow color, emits a strong unpleasant odor, and has a considerable degree of viscidity, properties which render it unfit for being burned in Argand lamps, and which are owing partly to the heat employed in its extraction, and partly to the presence of impurities. By purification, indeed, it may be rendered more limpid, and its odor less offensive; but it is always inferior to spermaceti oil.

1140. *Spermaceti.*—This inflammable substance is obtained from the fatty matter contained in the bony cavity of the head of the whale, (*Physeter macrocepalus*). On subjecting this substance to pressure, a quantity of pure limpid oil is expressed, called *spermaceti* oil; and the remainder, after being melted, strained, and boiled with a solution of potassa, is the solid spermaceti. It occurs in crystaline plates of a white color and silvery lustre; is very brittle, and soft, and slightly unctuous to the touch. It has no taste, and scarcely any odor. It is insoluble in water, but dissolves in about thirteen times its weight of boiling alcohol, from which the greater part is deposited on cooling in the form of brilliant scales. It is still more soluble in ether. It is exceedingly fusible, liquefying at a temperature which is distinctly below 212°.

The spermaceti of commerce always contains some fluid oil, from which it may be purified by solution in boiling alcohol. To the white crystaline scales deposited from the spirit as it cools, and which is spermaceti in a state of perfect purity, Chevreul has given the name *cetine.*

1141. *Hogslard.*—This fat is of a nearly white color, and the fusing point of different varieties between 79° and 88°. It probably contains both stearine and margarine besides oleine. When saponified, it yields margaric, stearic, and oleic acids, and glycerine.

1142. *Suet.*—This term is applied to the fat situated about the loins and kidneys, which is less fusible than the fat from other parts of the same animal. The suet from the ox and sheep is principally used; when separated by fusion from the membrane in which it occurs, it is called tallow, and is extensively employed in the manufacture of soap and candles. Beef and mutton suet resemble hogslard in their constituents and in the products of saponification. Beef suet, when fused, congeals at 102°, and mutton suet at 98° or a few degrees higher.

SECTION II.

COMPOSITION OF THE BLOOD AND PHENOMENA OF RESPIRATION.

1143. *Composition of the Blood.*—The blood is distinguished from other animal fluids by its color, which is a florid red in the arteries, and of a dark purple tint in the veins. Its taste is slightly saline, its odor peculiar, and to the touch it seems somewhat unctuous. Its specific gravity is variable, but most commonly it is near 1.05; and in man its temperature is about 98° or 100°. While flowing in its vessels, or when recently drawn, it appears to the naked eye as a uniform homogeneous liquid; but if examined with a microscope of sufficient power, numerous red particles of a globular form are seen floating in nearly a colorless fluid.

When the blood is withdrawn from the system, these globules contract into a solid mass or *coagulum*, which entirely separates on standing from the liquid *serum*. This is a thin yellowish liquid, of sp. gr. about 1.03, and coagulates when heated to about 140°. It has a slight alkaline reaction, owing to the presence of soda, and contains a considerable quantity of albumen.

In the living body the blood also contains fibrin in solution, which, however, soon separates from the coagulum after its extraction from the system. Various salts also are found, as common salt, phosphates of lime, magnesia, and ammonia, and lactates of soda and magnesia.

1144. The relative proportion of the ingredients of the blood must necessarily vary independent of disease even in the same individual, according as the nutrition is scanty or abundant. Slight variations are also occasioned by difference of age and sex.

1145. The coloring matter of the blood, to which the term *hematosine* is applied, is so analogous in most of its chemical relations to albumen, that its complete separation from it is attended with great difficulty. It is obtained nearly pure by cutting the clot of blood into very thin slices with a sharp knife, soaking them repeatedly in distilled water, and letting them drain on bibulous paper after each immersion: the slices are then broken up in distilled water with a stick, briskly stirring in order to dissolve the coloring matter; and the filtered solution is evaporated to dryness in shallow capsules or dishes at a temperature of 80° or 100°.

Soluble hematosine, when quite dry, is black, with a lustre like jet in mass and red in powder or in thin layers, is insipid to the taste, and inodorous. In cold water it readily dissolves, forming a red liquid, which may be preserved without change for months. Its solution, like that of albumen, may be coagulated by heat as already mentioned; but when quite dry, it may be heated to 212° without being rendered insoluble. Alcohol and acids likewise precipitate it: the latter deepen its tint, and fall in combination with it: but the compounds of hematosine with the muriatic, sulphuric, and acetic acid may be dissolved in water by means of an excess of their acid. The alkalies do not precipitate the aqueous solution of hematosine; but its solution in hydrochloric acid yields red flocks on the addition of ammonia.

Hematosine consists of carbon, hydrogen, nitrogen, oxygen, and iron, and its formula, according to the best analyses, is $C_{44}H_{22}N_3O_6Fe$.

1146. From the presence of iron in hematosine, and its total absence in the other principles of the blood, chemists were induced to suspect that its peculiar color is in some way or other produced by that metal, an idea which received additional support from the known tendency of peroxide of iron to form salts of a red color. But this view, though plausible on these grounds, is in other respects improbable.

The iron in reality is to be considered as an integral part of the organic constitution of the substance. It amounts to nearly 7 per cent. of the hematosine.

1147. Although hematosine is the coloring material of the globules of blood, it is present only in small quantity, 100 parts of dried globules containing but 4 or 5 of pure hematosine. A solution of the colored globules in water, when exposed to the air, becomes of a brighter red color, being thus partially affected in the same manner as in the passage of the blood through the lungs of the living animal. The solution coagulates when heated to 155°.

1148. The coagulation of the blood consists in the agglutination of the fibrin it contains, and perhaps some essential change in the arrangement of its particles in consequence of the loss of vitality. The time required for the coagulation of the blood depends much upon temperature, being promoted by heat and retarded by cold. It has been found that blood which begins to coagulate in four minutes and a half in an atmosphere of 53°, undergoes the same change in two minutes and a half at 98°; and that which coagulates in four minutes at 98°, will become solid in one minute at 120°. On the contrary, blood which coagulates firmly in five minutes at 60°, will remain quite fluid for twenty minutes at the temperature of 40°, and require upwards of an hour for complete coagulation.

1149. The process of coagulation is influenced by exposure to the air. If atmospheric air be excluded, as by filling a bottle completely with recently drawn blood, and closing the orifice with a good stopper, coagulation is retarded. It is singular, however, that if blood be confined within the exhausted receiver of an air-pump, the coagulation is accelerated.

Some substances prevent the coagulation of blood. This effect is produced by a saturated solution of chloride of sodium, hydrochlorate of ammonia, nitre, and a solution of potassa. The coagulation, on the contrary, is promoted by alum and the sulphates of the oxides of zinc and copper. The blood of persons who have died a sudden violent death, by some kinds of poison, or from mental emotion, is usually found in a fluid state. Lightning is said to have a similar effect; but the point seems not to be entirely settled.

The cause of the coagulation of the blood has been the subject of much speculation among physiologists, and is as much a question at the present time as it ever was. The reason why the blood retains its fluidity, coursing its way through the various minute ramifications of the system, during life, but immediately coagulates when the vital principle has fled, yet remains one of the profound mysteries of nature.

All we can say is, the blood, whilst in connection with the living animal, participates in its life, and in consequence of it, retains its fluidity; but deprived of this vitality, it yields at once to other unknown influences which produce this effect.

1150. The blood may be diseased either by the excess or deficiency of one or more of its proper constituents, or from the presence of substances which are foreign to it. In acute inflammatory diseases, there is often a great increase in the quantity of fibrin; while in other diseases, as chlorosis, the fibrin is unaffected, but the albumen of the serum is diminished. In diabetes mellitus, traces of sugar are found in the blood, especially after meals (1007).

One familiar instance of diseased blood is jaundice, when bile enters the circulation and is distributed to every organized part of the body. Though the presence of bile in the blood during jaundice has been detected, yet its passage into the circulating mass appears so rapidly succeeded by its exit, that its detection in the blood itself is generally difficult. Urea has also been detected sometimes in very large quantity: it appears to be constantly present in the blood, whenever the secretion of urine is suppressed.

1151. The most remarkable kind of diseased blood which has yet been studied by chemists is that which occurs in cholera. During the progress of that disease, an enormous discharge takes place of a whitish-colored fluid similar to a mixture of boiled rice with water, an appearance occasioned by a white flaky matter floating in a nearly colorless liquid. The insoluble part has the character of fibrin; while the liquid portion is a weak solution of albumen, is faintly alkaline, and contains the same kind of salts as exist in the blood. On examining the blood itself, it is found to contain less water and more albumen and hematosine than healthy blood: the density of the serum is consequently greater than usual; its color is remarkably black even in the arteries; in some cases it is semi-fluid, and incapable of coagulating, having the appearance of tar; and the salts of the blood are often in unusually small quantity, being sometimes almost entirely wanting. On comparing the condition of the blood with that of the discharges, it is manifest that the latter contains all the ingredients of the blood except the red globules; but that the aqueous and saline parts pass out of the circulation more rapidly than the albuminous.

The cause of these changes is by no means understood, and, as always happens in such cases, there is a great variety of opinions with regard to it.

1152. *Phenomena of Respiration.*—In the living body the blood in the veins and arteries is well known to differ remarkably in color; in the former it is of a dark purple red, but in the latter, of a bright vermilion color. The change from the venous to the arterial state is effected in the living animal during the passage of the blood through the capillary vessels of the lungs, where it is exposed to the action of an extensive surface of atmospheric air, through the thin membranes which separate these from the air-vessels; and the arterial blood, in traversing the capillary system of the body, imparting nourishment to it, gradually assumes the dark-colored condition in which it is returned to the heart by the veins. The same change is produced when venous blood, just taken from the system, is brought in contact with atmospheric air, and is attended with the evolution of carbonic acid gas. It takes place more speedily when air is agitated with blood; it is still more rapid when pure oxygen is substituted for atmospheric air; and it does not occur at all when oxygen is entirely excluded. The quantity of carbonic acid developed very exactly corresponds with the oxygen which disappears; but when the blood and air are agitated together, part of the carbonic acid which would otherwise be found as gas, is absorbed by the serum. It appears certain, from the experiments of Christison, that the coloring matter is the part of the blood essentially concerned in the phenomenon; an inference which is drawn, not from the mere change of tint, but from the effect of the blood on the air varying with the quantity and condition of the coloring matter. In some fevers, as acute rheumatism, in which the circulation is rapid and the respiration free, the venous blood is found to be very florid, and to withdraw very little oxygen from air; and a similar scanty abstraction of oxygen is observed in dark venous blood, when its usual proportion of coloring matter is deficient.

1153. The conversion of the dark purple color of venous blood into the florid tint of that contained in the arteries, is familiarly expressed by the term *arterialization;* or, more strictly, this name is applied to a change in the constitution of the blood, which is accompanied and indicated by change of color, evolution of carbonic acid, and abstraction of oxygen from the air.

Chemists have differed about the origin of the carbonic acid. Some suppose that the blood, in circulating through the body, becomes charged with carbon in some unknown mode of combination, which causes the venous character; and that when such blood is exposed to the air, its redundant carbon, by a process of oxydation, unites directly with atmospheric oxygen, the carbonic acid so generated is set free, and the blood unloaded of carbon recovers the arterial character. By others venous blood is thought to owe its color to the presence of carbonic acid ready formed within it; they maintain that oxygen gas is directly absorbed into the blood, and displaces the pre-existing carbonic acid (1158).

1154. But arterialization does not alone depend, as was thought till lately, on the influence of the atmosphere. Stevens, in his treatise on the blood, has the merit of proving the saline matter of the serum to be essential to the phenomenon. Various salts, such as nitre, chlorate of potassa, sea-salt, and bicarbonate of soda, have the property of giving to hematosine, or the coloring principle of the blood, a bright red tint, far more florid, when a strong saline solution is used, than arterial blood. A saline solution of the requisite strength gives to venous blood the arterial tint, without exposure to the air; but the serum contains so small a quantity of salt that its effect becomes visible only when aided by the agency of the atmosphere. A clot of venous blood, when carefully separated from its serum, is not brightened by oxygen gas; and arterial blood, when its serum is displaced by pure water, becomes as dark as venous blood. Hence it may be inferred that the change from venous to arterial blood consists of two parts, which are essentially distinct: one is attended with the direct absorption of oxygen, and the evolution of carbonic acid pre-existing in venous blood, an action essential to life; and the other, the most conspicuous but probably the least essential, is the effect of the saline parts of the serum, which impart a florid tint to the coloring matter after the former change has occurred. By what means the absorption of oxygen gives rise to the evolution of carbonic acid, is a question which, like others that will occur to the attentive reader, has not been sufficiently explained, and invites further investigation.

1155. The same changes which occur in blood out of the body are continually taking place within it. During respiration, venous blood is exposed in the lungs to the agency of the air and is arterialized, oxygen gas disappears, and carbonic acid is evolved; and it is remarkable that these phenomena ensue not only during life, but even after death, provided the respiratory process be preserved artificially. Since, therefore, all the characteristic phenomena of arterialization are the same in a living and in a dead animal, and whether the blood is or is not contained in the body, it seems legitimate to infer that this process is not necessarily dependent on the vital principle, but is solely determined by the laws of chemical action.

The absorption of oxygen and the evolution of carbonic acid gas during respiration have been long known, but many of the attending circumstances yet remain unsettled.

1156. The quantity of oxygen withdrawn from the atmosphere, and of carbonic acid disengaged, is variable in different individuals, and in the same individual at different times. From the observations of Prout, it appears that the quantity of carbonic acid emitted from the lungs is variable at particular periods of the day, and in particular states of the system. It is more abundant during the day than the night; about day-break it begins to increase, continues to do so till about noon, and then decreases until sunset. During the night it seems to remain uniformly at a minimum; and the maximum quantity given off at noon exceeds the minimum by about one-fifth of the whole. The quantity of carbonic acid is diminished by any debilitating causes, such as low diet, depressing passions, and the like.

1157. Although in respiration the arterialization of the blood by means of free oxygen is the essential change, without the due performance of which the life of warm-blooded animals cannot be preserved beyond a few minutes, and which is likewise necessary to the lowest of the insect tribe, it is important to determine whether the nitrogen of the atmosphere has any influence in the function. The results of different inquirers differ considerably; but it is now well ascertained that nitrogen is sometimes at least absorbed, and the probability is, it is not entirely passive in the important functions of respiration.

1158. Two theories have been proposed to explain the phenomena of respiration. According to one theory the carbonic acid found in the respired air is actually generated in the lungs themselves; while, according to the other, this gas is thought to exist ready formed in the blood, and to be merely thrown off from that liquid during its distribution through the lungs.

It is now very well ascertained that the oxygen of the air in the lungs is absorbed by the blood, and carried by the circulation to every part of the body, where it combines with the carbon which is present in excess, producing the carbonic acid that is thrown off in the lungs. It is found by examination that both arterial and venous blood hold in solution quantities of oxygen, nitrogen, and carbonic acid; but in arterial blood the quantity of oxygen is much greater in proportion to the carbonic acid than in venous blood, while the quantity of nitrogen is the same in both.

Formerly it was not known how the air is able to act upon the blood in the lungs, inasmuch as the air-cells and those containing the blood are separated from each other by membranes; but it is now fully settled that animal and other membranes are permeable by the different gases (409).

1159. *Animal Heat.*—It has long been known that there is a close connection between the function of respiration and the development of heat in the animal system, though the precise nature of this connection is not even now fully understood.

Thus in all animals whose respiratory organs are small and imperfect, and which, therefore, consume but a comparatively minute quantity of oxygen, and generate little carbonic acid, the temperature of the blood varies with that of the medium in which they live. In warm-blooded animals, on the contrary, in which the respiratory apparatus is larger, and the chemical changes more complicated, the temperature is almost uniform;

and those have the highest temperature whose lungs, in proportion to the size of their bodies, are largest, and which consume the greatest quantity of oxygen. The temperature of the same animal at different times is connected with the state of the respiration. When the blood circulates sluggishly, and the temperature is low, the quantity of oxygen consumed is comparatively small; but, on the contrary, a large quantity of that gas disappears when the circulation is brisk and the power of generating heat energetic. It has also been observed, that when an animal is placed in a very warm atmosphere, so as to require little heat to be generated within his own body, the consumption of oxygen is unusually small, and the blood within the veins retains the arterial character.

1160. The first consistent theory of the production of animal heat was proposed by Crawford. This theory was founded on the assumption that the carbonic acid contained in the breath is generated in the lungs, and that its formation is accompanied with disengagement of caloric. But since the temperature of the lungs is not higher than that of other internal organs, and arterial very little if at all warmer than venous blood, it follows that the greater part of the caloric, instead of becoming free, must in some way or other be rendered insensible. Accordingly, on comparing the specific caloric of arterial and venous blood, Crawford found the capacity of the former to exceed that of the latter in the ratio of 1030 to 892. He, therefore, inferred that the dark blood within the veins, at the moment of being arterialized, acquires an increase of insensible caloric; and that while circulating through the body, and gradually resuming the venous character, it suffers a diminution of capacity and evolves a proportional degree of heat.

Unfortunately for this hypothesis of Crawford, beautiful as it is, it seems not to be sustained by facts. It is very well ascertained that there is little if any difference in the capacities for caloric of venous and arterial blood; and if it is so, the hypothesis of course falls to the ground.

1161. Other theories have been proposed, but none of them appear to have been generally received. Some physiologists have even denied that there is any connection between animal heat and respiration, and ascribed the evolution of heat in the system entirely to the influence of the nervous system; but this is probably erroneous. The probability is entirely in favor of the opinion that the temperature of the system is kept up neither by respiration or nervous influence alone, but by the two combined, aided perhaps by other functions.

SECTION III.

CHEMICAL PHENOMENA OF DIGESTION.

1162. The phenomena of digestion are various and complicated, and are produced by the joint action of several substances, as the saliva, the gastric juice, and the bile.

1163. *Saliva.*—The saliva is a slightly viscid liquor, secreted by the salivary glands. When mixed with distilled water, a flaky matter subsides, which is mucus, derived apparently from the lining membrane of the mouth. The clear solution, when exposed to the agency of galvanism, yields a coagulum, and is hence inferred to contain albumen; but the quantity of this principle is so very small, that its presence cannot be demonstrated by any other reagent. The greater part of the animal matter remaining in the liquid is peculiar to the saliva, and may be termed *salivary matter*. It is soluble in water, insoluble in alcohol, and when freed from the accompanying salts, is not precipitated by subacetate of lead, corrosive sublimate, or infusion of gall-nuts.

The only known use of the saliva is to form a soft pulpy mass with the food during mastication, so as to reduce it into a state fit for being swallowed with facility, and for being more readily acted on by the juices of the stomach.

Concretions are sometimes found in the salivary glands and ducts of animals, but not often in the human subject. The deposition of tartar, as it is called, upon the teeth takes place chiefly or wholly from the saline and other substances contained in the saliva.

1164. *Pancreatic Juice.*—This fluid has generally been supposed to be analogous to the saliva, but recent experiments indicate that it is essentially different. The chief animal matters are albumen, and a substance like curd; but it also contains a small quantity of salivary matter and osmazome. It reddens litmus paper, owing to the presence of free acid, which is supposed to be the acetic. Its salts are nearly the same as those contained in the saliva, except that sulphocyanic acid is wanting.

1165. *Gastric Juice.*—The gastric juice, collected from the stomach of an animal killed while fasting, is a transparent fluid which has a saline taste, and has neither an acid nor alkaline reaction. During the process of digestion, on the contrary, it is found to be distinctly acid. This effect is occasioned also by the presence of flint stones or other indigestible matters; but it is produced in a still greater degree by substances of a stimulating nature. According to observation the acidity is owing to the secretion of free hydrochloric and acetic acids.

1166. The gastric juice coagulates milk, apparently in consequence of the acid secreted during digestion. It is highly antiseptic, not only preventing putrefaction, but rendering meat fresh after it is tainted. But of all the properties of the gastric juice, its solvent virtue is the most remarkable, being that on which depends the first stage of the process of digestion. When the food is introduced into the stomach, it is there intimately mixed with the gastric juice, by the agency of which it is dissolved, and converted into a semi fluid matter called *chyme*. That this change is owing to the solvent power of the gastric juice has been fully determined; and it seems to be well established as a further fact, that the gastric juice secreted in the stomachs of animals of any species is especially adapted for dissolving the particular kind of food upon which the species usually feed. Thus the gastric juice of animals that live chiefly upon animal food is found to possess the power of dissolving flesh readily, while it is capable of acting but slightly upon vegetable substances; but in animals that subsist chiefly upon vegetables, these substances are readily dissolved, though little effect is produced upon animal matter. The gastric juice of the human stomach seems to possess the power of dissolving with equal facility both animal and vegetable food.

Great diversity of opinion has prevailed respecting the cause of the solvent property of the gastric fluid. But it is now well settled that it depends upon a peculiar principle called *pepsine*, secreted by the mucous membrane of the stomach and other organs, aided by the free acids above mentioned, (1165), which are present in small quantity, and a little common salt, and hydrochlorate of ammonia. That the acids are important is shown by the fact that the solvent power of the juice is much diminished by neutralizing them by magnesia.

1167. *Bile.*—The bile is a yellow or greenish-yellow colored fluid, of a peculiar sickening odor, and of a taste at first sweet and then bitter, but exceedingly nauseous. Its consistence is variable, being sometimes limpid, but more commonly viscid and ropy. It is rather denser than water, and may be mixed with that liquid in every proportion. It contains a minute quantity of free soda, and is, therefore, slightly alkaline; but owing to the color of the bile itself, its action on test paper is scarcely visible.

The chemical constitution of the bile has been a subject of study by many learned chemists, but has not yet been satisfactorily determined. A peculiar substance called *picromel*, seems to be one essential ingredient.

The derangement which takes place in the system when the secretion of bile or its passage in the intestines is arrested, is a sufficient indication of the importance of this fluid. It acts as a stimulus to the intestine canal generally, and produces on the chyme some peculiar change, which is essential to its conversion into chyle.

1168. *Chyle.*—This substance produced as just shown from chyme, is absorbed from the small intestines by the lacteal vessels during the process of digestion. Its appearance differs in various animals; but as collected from the thoracic duct of a mammiferous animal three or four hours after a meal, it is a white opaque fluid like milk, having a sweetish and slightly saline taste. In a few minutes after removal from the duct it becomes solid, and in the course of twenty-four hours separates into a firm coagulum, and a limpid liquid which may be called the serum of the chyle. The coagulum is an opaque white substance, of a slightly pink hue, insoluble in water, but soluble easily in the alkalies and alkaline carbonates. Some suppose it to be fibrin in an imperfect state, or a kind of intermediate principle between fibrin and albumen; but others believe it to be more nearly allied to the caseous matter of milk.

1169. *Cholesterine.*—This name (from χολη *bile*, and στερεος *solid*), is applied to the crystaline matter which constitutes the basis of most of the biliary concretions formed in the human subject. It is a white, brittle solid, of a crystaline lamellated structure and brilliant lustre, very much resembling spermaceti; but it is distinguished from that substance by requiring a temperature of 278° for fusion, and by not being convertible into soap when digested in a solution of potassa. It is free from taste and odor, and is insoluble in water. It dissolves freely in boiling alcohol, from which it is deposited on cooling in white pearly scales.

Cholesterine has been detected in the bile of man, and of several of the lower animals, such as the ox, dog, pig, and bear. It is frequently formed in parts of the body quite unconnected with the hepatic circulation, and appears to be a common product of deranged vascular action, and it is believed, may be formed in almost any part of the system.

SECTION IV.

VARIOUS ANIMAL SUBSTANCES NOT BEFORE DESCRIBED.

1170. *Milk.*—This well-known liquid, secreted by the females of the class *mammalia* for the nourishment of their young, consists of three distinct parts, the cream, curd, and whey, into which, by repose, it spontaneously separates. The cream, which collects upon its surface, is an unctuous yellowish-white opaque fluid, of agreeable flavor. According to Berzelius, 100 parts of cream of specific gravity 1.0244, consists of butter 4.5, caseous matter 3.5, and whey 92. By agitation, as in the process of churning, the butter assumes the solid form, and is thus obtained in a separate state. During the operation there is an increase of temperature amounting to about three or four degrees, oxygen gas is absorbed, and an acid is generated; but the absorption of oxygen cannot be an essential part of the process, since butter may be obtained by churning when atmospheric air is entirely excluded.

After the cream has separated spontaneously, the milk soon becomes sour, and gradually separates into a solid coagulum called curd, and a limpid fluid which is whey. This coagulation is occasioned by free acetic acid, and it may be produced at pleasure, either by adding a free acid, or by means of the fluid known by the name of *rennet*, which is made by infusing the inner coat of a calf's stomach in hot water. When an acid is employed, the curd is found to contain some of it, in combination, and may, therefore, be regarded as an insoluble compound of an acid with the caseous matter of milk. The action of rennet requires further examination: it confessedly acts by means of the gastric fluid which it contains, and hence its coagulating power, consistently with the facts stated in the last section, is referable to the acidity of that juice.

The curd of skim milk, made by means of rennet, and separated from the whey by washing with water, is generally considered to be *caseous matter*, or the basis of cheese in a state of purity. In this state it is a white, insipid, inodorous sub stance, insoluble in water, but readily soluble in the alkalies, especially in ammonia. By alcohol it is converted, like albumen and fibrin, into an adipocirous substance of a fetid odor; and, like the same substance, it may be dissolved by a sufficient quantity of acetic acid.

1171. *Eggs.*—New-laid eggs are rather heavier than water; but they become lighter after a time, in consequence of water evaporating through the pores of the shell, and air being substituted for it. An egg of ordinary size yields to boiling water about three-tenths of a grain of saline matter, consisting of the sulphates, carbonates, and phosphates of lime and magnesia, together with animal matter and a little free alkali.

Of an egg which weighs 1000 grains, the shell constitutes 106.9, the white 604.2, and the yolk 288.9 grains. The shell contains about two per cent. of animal matter, one per cent. of the phosphates of lime and magnesia, and the residue is carbonate of lime with a little carbonate of magnesia.

The white of eggs is composed chiefly of albumen, but contains also a portion of sulphur. The yolk contains albumen, a peculiar oil, and a large portion of phosphorus, which is without question, the source of the phosphoric acid contained in the bones. The source of the lime in the bones has not been ascertained.

1172. *Lymph.*—The surface of the cellular membrane is moistened with a peculiar limpid transparent fluid called *lymph*, which is in very small quantity during health, but collects abundantly in some dropsical affections. Brande collected it from the thoracic duct of an animal which had been kept without food for twenty-four hours. Its chief constituent is water, besides which it contains muriate of soda and albumen, the latter being in such minute quantity that it is coagulated only by the action of galvanism. Lymph does not affect the color of test paper; but when evaporated to dryness, the residue gives a green tint to the syrup of violets.

The fluid secreted by serous membranes in general, such as the pericardium, pleura, and peritoneum, is very similar to lymph. A substance not unlike it is secreted in various diseases.

1173. *Humors of the Eye.*—The aqueous and vitreous humors of the eye contain rather more than 80 per cent. of water. The other constituents are a small quantity of albumen, muriate and acetate of soda, pure soda, though scarcely sufficient to affect the color of test paper, and animal matter, soluble only in water, but which is not gelatin. The crystaline lens, besides the usual salts, contains 36 per cent. of a peculiar animal matter, very analogous to albumen if not identical with it. In cold water it is soluble, but is coagulated by boiling. The coagulum has all the properties f the coloring matter of the blood excepting its color.

The *tears* are limpid and of a saline taste, dissolve freely in water, and, owing to the presence of free soda, communicate a green tint to the blue infusion of violets. Their chief salts are chloride of sodium and phosphate of soda.

1174. *Mucus.*—The term *mucus* has been employed in very different significations. Bostock applies it to a peculiar animal matter which is soluble both in hot and cold water, is not precipitated by corrosive subli nate or solution of tannin, is not capable of forming a jelly, and which yields a precipitate with subacetate of lead. But the substance or substances which have received this name seem not to be very well defined.

1175. *Pus* is a fluid substance secreted by inflamed and ulcered surfaces. Its properties vary according to the nature of the sore from which it is discharged.

1176. *Sweat.*—Watery vapor is continually passing off by the skin in the form of insensible perspiration; but when the external heat is considerble, or violent bodily exercise is taken, drops of fluid collect upon the surface, and constitute what is called sweat. This fluid consists chiefly of water; but contains some muriate of soda and free acetic acid, in consequence of which it has a saline taste and an acid reaction.

1177. *Urine.*—The urine differs from most of the animal fluids which have been described, by not serving any ulterior purpose in the animal economy. It is merely an excretion designed for ejecting from the system substances, which, by their accumulation within the body, would speedily prove fatal to health and life. The sole office of the kidneys, indeed, appears to consist in separating from the blood the superfluous matters that are not required or adapted for nutrition, or which have already formed part of the body, and been removed by absorption. The substances which in particular pass off by this organ are nitrogen, in the form of highly azotized products, and various saline and earthy compounds. This sufficiently accounts for the great diversity of substances contained in urine.

1178. The quantity of the urine is affected by various causes, especially by the nature and quantity of the liquids received into the stomach; but on an average, a healthy person voids between thirty and forty ounces daily. The quality of this fluid is likewise influenced by the same circumstances, being sometimes in a very dilute state, and at others highly concentrated. The urine voided in the morning by a person who has fed heartily, and taken no more fluids than is sufficient for satisfying thirst, may be regarded as affording the best specimen of natural healthy urine.

The urine in this state is a transparent limpid fluid of an amber color, having a saline taste, and while warm emitting an odor which is slightly aromatic, and not at all disagreeable.

Its specific gravity is about 1.022. It gives a red tint to litmus paper, a circumstance which indicates the presence either of a free acid or of a supersalt. Though at first quite transparent, an insoluble matter is deposited on standing; so that urine, voided at night, is found to have a light cloud floating in it by the following morning. This substance consists in part of mucus from the urinary passages, and partly of superurate of ammonia, which is much more soluble in warm than in cold water.

1179. The urine is very prone to spontaneous decomposition. When kept for two or three days, it acquires a strong urinous smell; and as the putrefaction proceeds, the disagreeable odor increases, until at length it becomes exceedingly offensive. As soon as these changes commence, the urine ceases to have an acid reaction, and the earthy phosphates are deposited. In a short time, a free alkali makes its appearance, and a large quantity of carbonate of ammonia is gradually generated. Similar changes may be produced in recent urine by continued boiling. In both cases the phenomena are owing to the decomposition of urea, which is almost entirely resolved into carbonate of ammonia.

The composition of urine is exceedingly complicated, containing no less than twenty different substances. The most important organic compounds contained in it are urea and uric acid, which will be described.

1180. *Urea.*—This substance is always found in healthy urine, and, as intimated above (901), may be prepared artificially. It is best obtained from cyanate of ammonia, by roasting ferrocyanide of potassium, and boiling it in a solution of sulphate of ammonia. The whole is then to be boiled with alcohol, which dissolves out the urea, and leaves the solid sulphate of potassa. The urea readily crystalizes, on standing, from its solution in alcohol. Its crystals when pure are transparent and colorless, of a slight pearly lustre, and have commonly the form of a four-sided prism. It leaves a sensation of coldness on the tongue like nitre, and its smell is faint and peculiar, but not urinous. Its specific gravity is about 1.35. It does not affect the color of litmus or turmeric paper. In a moist atmosphere it deliquesces slightly; but otherwise it undergoes no change on exposure to the air.

1181. Water at 60° dissolves more than its own weight of urea, and boiling water takes up an unlimited quantity. It requires for solution about five times its weight of alcohol of specific gravity 0.816 at 60°, and rather less than its own weight at a boiling temperature. The aqueous solution of pure urea may be exposed to the atmosphere for several months, or be heated to the boiling point, without change; but on the contrary, if the other constituents of urine are present, it putrefies with rapidity, and is decomposed by a temperature of 212°, being almost entirely resolved into carbonate of ammonia by continued ebullition.

The pure fixed alkalies and alkaline earths decompose urea, especially by the aid of heat, carbonate of ammonia being the chief product.

1182. Though urea has not any distinct alkaline properties, it unites with the nitric and oxalic acids, forming sparingly soluble compounds, which crystalize in scales of a pearly lustre.

This property affords an excellent test of the presence of urea. Both compounds have an acid reaction, and the nitrate consists of 54.15 parts or one equivalent of nitric acid, and 60.54 parts or one equivalent of urea.

The composition of urea is exhibited by the following formula, $N_2C_2O_2H_4$:—Eq. 60.54.

1183. *Uric Acid.*—This acid is a common constituent of urinary and gouty concretions, and is always present in healthy urine, combined with ammonia or some other alkali. The urine of birds of prey, such as the eagle, and of the *boa constrictor*, and other serpents, consists almost solely of urate of ammonia, from which pure uric acid may be procured by a very simple process.

Pure uric acid is white, tasteless, and inodorous. It is insoluble in alcohol, and is dissolved very sparingly by cold or hot water, requiring about 10,000 times its weight of that liquid at 60° for solution. It reddens litmus paper, and unites with alkalies, forming salts which are called *urates*.

The formula for uric acid is $N_4C_{10}H_4O_6$.

1184. The substance called *guano* which is brought to South America and to Europe from some of the South Sea islands, and used for manure, is chiefly *urate of ammonia*. The islands on which it is found are constantly inhabited by immense numbers of aquatic birds; and it is from their excrements the substance accumulates.

1185. *Urinary Concretions.*—In consequence of the complicated nature of urine (1179), and the diseased action to which the system is subject, depositions of solid matter from the urine often take place within the bladder, giving rise to one of the worst class of evils that afflict humanity.

The most common kinds of urinary concretions may be conveniently divided into the six following species:

1. The uric acid calculus, which is a hard inodorous concretion, usually of an oval form, and brown color. It is soluble in several of the acids, and in pure potassa.

2. The bone earth calculus, which consists almost solely of phosphate of lime. Its structure is usually laminated; and when reduced to powder, it is soluble in dilute nitric and muriatic acid.

3. The ammoniaco-magnesian phosphate, which is generally of a white color, and when reduced to powder, is dissolved with great facility by the acetic and other acids.

4. The fusible calculus, which is considered a mixture of the two preceding species, and is characterized by the facility with which it melts into a globule. It is one of the most common, and is sometimes very large.

5. The mulberry calculus, so named from its resemblance to the fruit of the mulberry. It is composed of oxalate of lime, and is soluble in hydrochloric acid when reduced to powder, but not in the acetic, by which it is distinguished from some of the preceding species.

6. The cystic oxide calculus, which is very rare, and is never accompanied by any of the other concretions. It is dissolved by nearly all the acids and several alkaline solutions, and even by lime-water.

Several of these species often accompany each other, and form the *compound* calculus; and frequently the concretion consists of alternate layers constituting the *alternating* calculus.

From the solubility of urinary concretions in chemical menstrua, hopes were once entertained that reagents might be introduced into the urine through the medium of the blood, or be at once injected into the bladder so as to dissolve urinary calculi, and thus supersede the necessity of a painful and dangerous operation. It has been found, however, that for this purpose, it would be necessary to employ acid or alkaline solutions of greater strength than may safely be introduced into the bladder; and it is therefore very doubtful whether anything effectual will by this method ever be accomplished.

Oil of Dippel.—This is the name given to a limpid volatile oil, which is a product of the destructive distillation of animal substances, especially those which contain a large proportion of albumen and gelatine. When purified by distillation, it is clear and transparent; and was formerly much used in medicine.

1186. *Ambergris.*—This substance is found floating on the surface of the sea near the coasts of India, Africa, and Brazil, and is supposed to be a concretion formed in the stomach of the spermaceti whale. It has commonly been regarded as a resinous principle; but its chief constituent is a substance very analogous to cholesterine, and to which the name of *ambreine* has been given.

Ethal, *adipocire*, and *hircine* are other animal substances of a similar character.

PART IV.

ANALYTICAL CHEMISTRY.

THE object of Analytical Chemistry is to determine the nature, proportions, and mode of combination of the elements of the various compounds which occur in nature, or are produced by art.

It is an exceedingly important branch of the science; but only a few pages can be introduced into an elementary work like the present, merely to show something of its nature and design. Our remarks may be conveniently divided into four sections, which treat of the analysis of the mixed gases, of minerals, of mineral waters, and of organic analysis.

In general it is comparatively easy to determine the ingredients contained in a compound or its *qualative analysis;* but it is much more difficult to ascertain the proportions in which they are combined, or its *quantative analysis.*

SECTION I.

ANALYSIS OF MIXED GASES.

Analysis of Air or of Gaseous mixtures containing Oxygen.—Of the various processes by which oxygen gas may be withdrawn from gaseous mixtures, and its quantity determined, none are so convenient and precise as the method by means of hydrogen gas. In performing this analysis, a portion of atmospheric air is carefully measured in a graduated tube, and mixed with a quantity of hydrogen gas which is rather more than sufficient for uniting with all the oxygen present. The mixture is then introduced into a strong glass tube, and a spark is passed through it by means of conducting wires fixed into the tube. The aperture is closed by the thumb at the moment of detonation, in order to prevent any of the mixture from escaping. The total diminution in volume divided by three indicates the quantity of oxygen originally contained in the mixture. This operation may be performed in a trough either of water or mercury. Instead of electricity, spongy platinum may be employed for causing the union of oxygen and hydrogen gases; and while its indications are very precise, it has the advantage of producing the effect gradually and without detonation.

To insure accuracy the hydrogen of course should be perfectly pure.

Mode of determining the Quantity of Nitrogen in Gaseous Mixtures.—As atmospheric air, which has been deprived of moisture and carbonic acid, consists of oxygen and nitrogen only, the proportion of the latter is of course known as soon as that of the former is determined. The only method, indeed, by which chemists are enabled to estimate the quantity of this gas, is by withdrawing the other gaseous substances with which it is mixed.

Mode of determining the Quantity of Carbonic Acid in Gaseous Mixture.—When carbonic acid is the only acid gas which is present, as in analyzing atmospheric air, in the ultimate analysis of organic compounds, and in most other analogous researches, the process for determining its quantity is exceedingly simple; for it consists merely in absorbing that gas by lime-water or a solution of caustic potassa. This is easily done in the course of a few minutes in an ordinary graduated tube; or it may be effected almost instantaneously by agitating the gaseous mixture with the alkaline solution in Hope's eudiometer. This apparatus consists simply of a strong glass tube closed at one end and properly graduated and ground into the neck of a vial to contain the alkaline solution. This vial should also have an additional neck and ground stopper. By inverting the instrument the gases may be made to pass through the alkaline solution, by which the carbonic acid will be absorbed; and by removing the stopper in the body of the eudiometer, under water, the water will rush in and its rise in the tube will show the amount of the absorption, and of course the proportion of carbonic acid gas contained in the mixture analyzed. By using a substance capable of absorbing oxygen, as the hydrosulphate of potassa instead of the alkaline solution, it is evident this gas might be separated from a mixture in which it is contained in an uncombined state.

Mode of analyzing Mixtures of Hydrogen and other Inflammable Gases.—When hydrogen is mixed with nitrogen, oxygen or atmospheric air, its quantity is easily ascertained by causing it to combine with oxygen either by means of platinum or the electric spark. If, instead of hydrogen, any other combustible substance, such as carbonic oxide, light carburetted hydrogen, or olefiant gas, be mixed with nitrogen, the analysis is easily effected by adding a sufficient quantity of oxygen, and detonating the mixture by electricity. The diminution in volume indicates the quantity of hydrogen contained in the gas, and from the carbonic acid which may then be removed by an alkali, the quantity of carbon is inferred.

Other methods must of course be devised to analyze particular mixtures, but the above processes, or some slight modifications of them, may generally be adopted.

SECTION II.

ANALYSIS OF MINERALS.

THIS department of analytical chemistry is very extensive, and to give an idea of the manner in which the analysis of minerals is effected, a few selections will be made of the most common minerals. The usual constituents of these are silica, alumina, iron, manganese, lime, magnesia, potassa, soda and carbonic and sulphuric acids. To some of the compounds formed by these substances our attention will therefore be directed.

In attempting to separate two or more fixed principles from each other, the first object of the analytical chemist is to bring them into a state of solution. If they are soluble in water, this fluid is preferred to every other menstruum; but if not, an acid or any convenient solvent may be employed. In many instances, however, the substance to be analyzed resists the action even of the acids, and in that case the following method is adopted:—The compound is first crushed by means of a hammer or steel mortar, and is afterwards reduced to an impalpable powder in a mortar of agate: it is then intimately mixed with three, four, or more times its weight of potassa, soda, baryta, or their carbonates; and, lastly, the mixture is exposed in a crucible of silver or platinum to a strong heat. During the operation, the alkali combines with one or more of the constituents of the mineral; and, consequently, its elements being disunited, it no longer resists the action of the acids.

Analysis of Marble or Carbonate of Lime.—This analysis is easily made by exposing a known quantity of marble for about half an hour to a full white heat, by which means the carbonic acid gas is entirely expelled, so that by the loss in weight the quantity of each ingredient, supposing the marble to have been pure, is at once determined. In order to ascertain that the whole loss is owing to the escape of carbonic acid, the quantity of this gas may be determined by a comparative analysis. Into a small flask containing hydrochloric acid, diluted with two or three parts of water, a known quantity of marble is gradually added, the flask being inclined to one side in order to prevent the fluid from being flung out of the vessel during the effervescence. The diminution in weight experienced by the flask and its contents, indicates the quantity of carbonic acid which has been expelled.

Should the carbonate suffer a greater loss in the fire than when decomposed by an acid, it will most probably be found to contain water. This may be ascertained by heating a piece of it to redness in a glass tube, the sides of which will be bedewed with moisture, if water is present. Its quantity may be determined by causing the watery vapor to pass through a weighed tube filled with fragments of the chloride of calcium, by which the moisture is absorbed.

Separation of Lime and Magnesia.—The more common kinds of carbonate of lime frequently contain traces of siliceous and aluminous earths, in consequence of which they are not completely dissolved in dilute hydrochloric acid. A very frequent source of impurity is carbonate of magnesia, which is often present in such quantity that it forms a peculiar compound called *magnesian limestone.* The analysis of this substance, so far as respects carbonic acid, is the same as that of marble. The separation of the two earths may be conveniently effected in the following manner:—The solution of the mineral in muriatic acid is evaporated to perfect dryness in a flat dish or *capsule* of porcelain, and after redissolving the residuum in a moderate quantity of distilled water, a solution of oxalate of ammonia is added as long as a precipitate ensues. The oxalate of lime is then allowed to subside, collected on a filter, converted into quicklime by a white heat, and weighed; or the oxalate may be decomposed by a red heat, and after moistening the resulting carbonate with a strong solution of the carbonate of ammonia, in order to supply any particles of quicklime with carbonic acid, it should be dried, heated to low redness, and regarded as pure carbonate of lime. To the filtered liquid, containing the magnesia, a mixture of pure ammonia and phosphate of soda is added, when the magnesia, in the form of the ammoniaco-phosphate, is precipitated. Of this precipitate heated to redness, 100 parts correspond to 37 of pure magnesia.

To insure perfect accuracy, many precautions are to be attended to.

Earthy Sulphates.—The most abundant of the earthy sulphates is that of lime, the analysis of which is easily effected. By boiling it for fifteen or twenty minutes with a solution of twice its weight of carbonate of soda, double decomposition ensues; and the carbonate of lime, after being collected on a filter and washed with hot water, is either heated to low redness to expel the water, and weighed, or at once reduced to quicklime by a white heat. Of the dry carbonate, 50 parts correspond to 28 of lime. The alkaline solution is acidulated with hydrochloric acid, and the sulphuric acid thrown down by chloride of barium. From the sulphate of baryta, collected and dried at a red heat, the quantity of acid may easily be estimated.

The method of analyzing the sulphate of strontia and baryta is somewhat different. As these salts are difficult of decomposition in the moist way, the following process is adopted:—The sulphate, in fine powder, is mixed with three times its weight of carbonate of soda, and the mixture is heated to redness in a platinum crucible for the space of an hour. The ignited mass is then digested in hot water, and the insoluble earthy carbonate collected on a filter. The other parts of the process are the same as the foregoing.

Mode of Analyzing Compounds of Silica, Alumina, and Iron.—Minerals, thus constituted, are decomposed by an alkaline carbonate at a red heat, in the same manner as sulphate of baryta. The mixture is afterwards digested in dilute hydrochloric acid, by which means all the ingredients of the mineral, if the decomposition is complete, are dissolved. The solution is next evaporated to dryness, the heat being carefully regulated towards the close of the process, in order to prevent any of the chloride of iron, the volatility of which is considerable, from being dissipated in vapor. By this operation, the silica, though previously held in solution by the acid, is entirely deprived of its solubility; so that on digesting the dry mass in water acidulated with hydrochloric acid, the alumina and iron are taken up, and the silica is left in a state of purity. The siliceous earth, after subsiding, is collected on a filter, carefully edulcorated, heated to redness, and weighed.

To the clear liquid, containing peroxide of lime and alumina, a solution of pure potassa is added in moderate excess; so as not only to throw down those oxides, but to dissolve the alumina. The peroxide of iron is then collected on a filter, edulcorated carefully until the washings cease to have an alkaline reaction, and is well dried on a sand-bath. Of this hydrated peroxide, 49 parts contain 40 of anhydrous peroxide of iron. But the most accurate mode of determining its quantity is by expelling the water by a red heat. This operation, however, should be done with care; since any adhering particles of paper, or other combustible matter, would bring the iron into the state of black oxide, a change which is known to have occurred by the iron being attracted by a magnet.

To procure the alumina, the liquid in which it is dissolved is boiled with hydrochlorate of ammonia, when chloride of potassium is formed, the volatile alkali is dissipated in vapor, and the alumina subsides. As soon as the solution is thus rendered neutral, the hydrous alumina is collected on a filter, dried by exposure to a white heat, and quickly weighed after removal from the fire.

Separation of Iron and Manganese.—A compound of these metals or their oxides may be dissolved in hydrochloric acid. If the iron is in a large proportion compared with the manganese, the following process may be adopted with advantage: To the cold solution, considerably diluted with water, and acidulated with hydrochloric acid, carbonate of soda is gradually added, and the liquid is briskly stirred with a glass rod during the effer vescence, in order that it may become highly charged with carbonic acid. By neutralizing the solution in this manner, it at length attains a point at which the peroxide of iron is entirely deposited, leaving the liquid colorless; while the manganese, by the aid of the free carbonic acid, is kept in solution. The iron, after subsiding, is collected on a filter, and its quantity determined in the usual manner. The filtered liquid is then boiled with an excess of carbonate of soda; and the precipitated carbonate of manganese is collected, heated to full redness in an open crucible, by which it is converted into the red oxide, and weighed. This method is one of some delicacy; but in skilful hands, it affords a very accurate result. It may also be employed in separating iron from magnesia and lime as well as from manganese.

But if the proportion of iron is small compared with that of manganese, the best mode of separating it is by succinate of ammonia or soda, prepared by neutralizing a solution of succinic acid with either of those alkalies. That this process should succeed, it is necessary that the iron be wholly in the state of peroxide, that the solution be exactly neutral, which may easily be insured by the cautious use of ammonia, and that the reddish-brown colored succinate of peroxide of iron be washed with cold water. Of this succinate, well dried at a temperature of 212°, 90 parts correspond to 40 of the peroxide. From the filtered liquid the manganese may be precipitated at a boiling temperature by carbonate of soda, and its quantity determined in the way above mentioned. The benzoate may be substituted for succinate of ammonia in the preceding process.

It may be stated as a general rule, that whenever it is intended to precipitate iron by means of the alkalies, the succinates, or benzoates, it is essential that this metal be in the maximum of oxydation. It is easily brought into this state by digestion with a little nitric acid.

Separation of Manganese from Lime and Magnesia.—If the quantity of the former be proportionally small, it is precipitated as a sulphuret by hydrosulphate of ammonia or sulphuret of potassium. The sulphuret is then dissolved in hydrochloric acid, and the manganese thrown down as usual by means of an alkali. But if the manganese be the chief ingredient, the best method is to precipitate it at once, together with the two earths, by a fixed alkaline carbonate at a boiling temperature. The precipitate, after being exposed to a low red heat and weighed, is put into cold water acidulated with a drop or two of nitric acid, when the lime and magnesia will be slowly dissolved with effervescence. Should a trace of the manganese be likewise taken up, it may easily be thrown down by hydrosulphate of ammonia.

Stromeyer has recommended a very elegant and still better process for removing small quantities of manganese from lime and magnesia. The solution is acidulated with nitric or hydrochloric acid, bicarbonate of soda is gradually added in very slight excess, stirring after each addition, that the liquid may be charged with carbonic acid, and a solution of chlorine, or a current of the gas, is introduced. The protoxide of manganese is converted by the chlorine into the insoluble hydrated peroxide, while any traces of lime or magnesia, which might otherwise fall, are retained in solution by means of carbonic acid. A solution of chloride of soda or lime is in fact our most delicate test for small quantities of manganese.

Mode of analyzing an Earthy Mineral containing Silica, Iron, Alumina, Manganese, Lime, and Magnesia.—The mineral, reduced to fine powder, is ignited with three or four times its weight of carbonate of potassa or soda, the mass is taken up in dilute hydrochloric acid, and the silica separated in the way already described. To the solution, thus freed from silica and duly acidulated, carbonate of soda, or still better, the bicarbonate, is gradually added, so as to charge the liquid with carbonic acid, as in the analysis of iron and manganese. In this manner the iron and alumina are alone precipitated, substances which may be separated from each other by means of pure potassa. The manganese, lime, and magnesia may then be determined by the processes above described.

Analysis of Minerals containing a Fixed Alkali.—When the object is to determine the quantity of fixed alkali, such as potassa or soda, it is of course necessary to abstain from the employment of these reagents in the analysis itself; and the beginner will do well to devote his attention to the alkaline ingredients only. On this supposition, he will proceed in the following manner: The mineral is reduced to a very fine powder, mixed intimately with six times its weight of artificial carbonate of baryta, and exposed for an hour to a white heat. The ignited mass is dissolved in dilute hydrochloric acid, and the solution evaporated to perfect dryness. The soluble parts are taken up in hot water; an excess of carbonate of ammonia is added; and the insoluble matters, consisting of silica, carbonate of baryta, and all the constituents of the mineral, excepting the fixed alkali, are collected on a filter. The clear solution is evaporated to dryness in a porcelain capsule, and the dry mass is heated to redness in a crucible of platinum, in order to expel the salts of ammonia. This residue is chloride of potassium or sodium.

In this analysis, it generally happens that traces of manganese, and sometimes of iron, escape precipitation in the first part of the process; and, in that case, they should be thrown down by hydrosulphate of ammonia. If neither lime nor magnesia is present, the alumina, iron, and manganese may be separated by pure ammonia, and the baryta subsequently removed by the carbonate of that alkali. By this method the carbonate of baryta is recovered in a pure state, and may be reserved for another analysis. The baryta may also be thrown down as a sulphate by sulphuric acid, in which case the soda or potassa is procured in combination with that acid; but this mode is objectionable, because the sulphate of baryta is very apt to retain small quantities of sulphate of potassa.

The analysis is attended with considerable inconvenience when magnesia happens to be present; because this earth is not completely precipitated either by ammonia or its carbonate, and, therefore, some of it remains with the fixed alkali. The best mode with which, it is believed, is to precipitate the magnesia by phosphate of ammonia; subsequently separating from the filtered solution the excess of phosphoric acid by acetate of lead, and that of lead by hydrosulphuric acid. The acetate of the alkali is then brought to dryness, ignited, and by the addition of sulphate of ammonia converted into a sulphate.

The tests commonly employed in ascertaining the acidity or alkalinity of liquids are litmus and turmeric paper. The former is made by digesting litmus, reduced to a fine powder, in a small quantity of water, and painting with it white paper which is free from alum. Turmeric paper is made in a similar manner; but the most convenient test of alkalinity is litmus paper reddened by a dilute acid.

SECTION III.

ANALYSIS OF MINERAL WATERS.

RAIN water collected in clean vessels in the country, or freshly fallen snow when melted, affords the purest kind of water which can be procured without having recourse to distillation. The water obtained from these sources, however, is not absolutely pure, but contains a portion of carbonic acid and air, absorbed from the atmosphere. It is remarkable that this air is very rich in oxygen. That procured from snow water by boiling was found by Gay-Lussac and Humboldt to contain 34.8, and that from rain water 32 per cent. of oxygen gas. From the powerfully solvent properties of water, this fluid no sooner reaches the ground and percolates through the soil, than it dissolves some of the substances which it meets with in its passage. Under common circumstances it takes up so small a quantity of foreign matter, that its sensible properties are not materially affected: and in this state it gives rise to *spring*, *well*, and *river* water. Sometimes, on the contrary, it becomes so strongly impregnated with saline and other substances, that it acquires a peculiar flavor, and is thus rendered unfit for domestic uses. It is then known by the name of *mineral water*.

The composition of spring water is dependent on the nature of the soil through which it flows. If it has filtered through primitive strata, such as quartz rock, granite, and the like, it is in general very pure; but if it meets with limestone or gypsum in its passage, a portion of these salts is dissolved, and communicates the property called *hardness*. Hard water is characterized by decomposing soap, the lime of the former yielding an insoluble compound with the margaric and oleic acids of the latter. If this defect is owing to the presence of carbonate of lime, it is easily remedied by boiling, when free carbonic acid is expelled, and the insoluble carbonate of lime subsides. If sulphate of lime is present, the addition of a little carbonate of soda, by precipitating the lime, converts the hard into soft water. Besides these ingredients, the chlorides of calcium and sodium are frequently contained in spring water.

Spring water, in consequence of its saline impregnation, is frequently unfit for chemical purposes and on these occasions distilled water is employed. Distillation may be performed on a small scale by means of a retort, in the body of which water is made to boil, while the condensed vapor is received in a glass flask, called a *recipient*, which is adapted to its beak or open extremity. This process is more conveniently conducted, however, by means of a still.

The different kinds of mineral water may be conveniently arranged for the purpose of description in the six divisions of *acidulous*, *alkaline*, *chalybeate*, *sulphuretted*, *saline* and *siliceous* springs.

1. *Acidulous springs* commonly owe their acidity to the presence of free carbonic acid, in consequence of the escape of which they sparkle when poured from one vessel into another. Such carbonated waters communicate a red tint to litmus paper before, but not after being boiled, and the redness disappears on exposure to the air. Mixed with a sufficient quantity of lime-water, they become turbid from the deposition of carbonate of lime. They frequently contain the carbonates of lime, magnesia, and protoxide of iron, in consequence of the facility with which these salts are dissolved by water charged with carbonic acid.

The best mode of determining the quantity of carbonic acid is by heating a portion of the water in a flask, and receiving the carbonic acid, by means of a bent tube, in a graduated jar filled with mercury.

2. *Alkaline waters* are such as contain a free or carbonated alkali, and, consequently, either in their natural state or when concentrated by evaporation, possess an alkaline reaction.

These springs are rare.

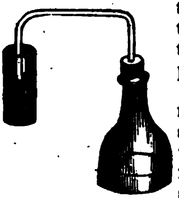
3. *Chalybeate waters* are characterized by a strong styptic, inky taste and by striking a black color with the infusion of gall-nuts. The iron is sometimes combined with hydrochloric or sulphuric acid; but most frequently it is in the form of protocarbonate, held in solution by free carbonic acid. On exposure to the air, the protoxide is oxydized, and the hydrated peroxide subsides, causing the ochreous deposite so commonly observed in the vicinity of chalybeate springs.

To ascertain the quantity of iron contained in a mineral water, a known weight of it is concentrated by evaporation, and the iron is brought to a state of peroxide by means of nitric acid. The peroxide is then precipitated by an alkali and weighed; and if lime and magnesia are present, it may be separated from those earths by the process described in the last section.

Chalybeate waters are not uncommon.

4. *Sulphuretted waters* contain hydrosulphuric acid, (498) and are easily recognized by their odor, and by causing a brown precipitate with a salt of lead or silver. The gas is readily expelled by boiling, and its quantity may be inferred by transmitting it through a solution of acetate of oxide of lead, and weighing the sulphuret which is generated. This is easily done by introducing a little of the water to be examined into a glass flask, figure 93, having a bent-tube inserted in its mouth through a perforated cork. If now the open end of the tube is plunged into a solution of acetate of lead, and the water made to boil, the hydrosulphuric acid, as it passes over, will be entirely absorbed by the lead.

Fig. 93.



5. Those mineral springs are called *saline*, the character of which is caused by saline compounds. The salts which are most frequently contained in these waters are the sulphates and carbonates of lime, magnesia, and soda, and the chlorides of calcium, magnesium, and sodium. Potassa sometimes exists in them, and Berzelius has found lithia in the spring of Carlsbad. It has lately been discovered that the presence of hydriodic acid in small quantity is not unfrequent.

The first object in examining a saline spring is to determine the nature of its ingredients. Hydrochloric acid is detected by nitrate of oxide of silver, and sulphuric acid by chloride of barium; and if an alkaline carbonate be present, the precipitate occasioned by either of these tests will contain a carbonate of oxide of silver or baryta. The presence of lime and magnesia may be discovered, the former by oxalate of ammonia, and the latter by phosphate of ammonia. Potassa is known by the action of chloride of platinum. To detect soda, the water should be evaporated to dryness, the deliquescent salts removed by alcohol, and the matter insoluble in that menstruum taken up by a small quantity of water, and allowed to crystalize by spontaneous evaporation. The salt of soda may then be recognized by the rich yellow color which it communicates to flame. If the presence of hydriodic acid be suspected, the solution is brought to dryness, the soluble parts dissolved in two or three drachms of a cold solution of starch, and strong sulphuric acid gradually added (561).

Having thus ascertained the nature of the saline ingredients, their quantity may be determined by evaporating a pint of water to dryness, heating to low redness, and weighing the residue. In order to make an exact analysis, a given quantity of the mineral water is concentrated in an evaporating basin as far as can be done without causing either precipitation or crystalization, and the residual liquid is divided into two equal parts. From one portion the sulphuric and carbonic acids are thrown down by nitrate of baryta; and after collecting the precipitate on a filter, the hydrochloric acid is precipitated by nitrate of oxide of silver. The mixed sulphate and carbonate is exposed to a low red heat, and weighed; and the latter is then dissolved by dilute hydrochloric acid, and its quantity determined by weighing the sulphate. The chloride of silver, of which 143.42 parts correspond to 36.42 of hydrochloric acid, is fused in a platinum spoon or crucible, in order to render it quite free from moisture. To the other half of the concentrated mineral water, oxalate of ammonia is added for the purpose of precipitating the lime; and the magnesia is afterwards thrown down as the ammoniaco phosphate, by means of ammonia and phosphoric acid. Having thus determined the weight of each of the fixed ingredients excepting the soda, the loss of course gives the quantity of that alkali; or it may be procured in a separate state by the process described in the foregoing section.

The individual constituents of the water being known, it remains to determine the state in which they were originally combined. In a mineral water containing sulphuric and hydrochloric acids, lime, and soda, it is obvious that three cases are possible. The liquid may contain sulphate of lime and chloride of sodium, or chloride of calcium and sulphate of soda; or each acid may be distributed between both the bases. In many complicated cases it is difficult to tell in what manner the several acids and bases contained in the water are united.

Sea-water may be regarded as one of the saline mineral waters. Its taste is disagreeably bitter and saline, and its fixed constituents amount to about three per cent. Its specific gravity varies from 1.0269 to 1.0285; and it freezes at about 28.5°. According to the analysis of Murray, 10,000 parts of water from the Frith of Forth contain 220.01 parts of common salt, 33.16 of sulphate of soda, 42.08 of hydrochlorate of magnesia, and 7.84 of hydrochlorate of lime. Wollaston detected potassa in sea-water, which likewise contains small quantities of hydriodic and hydrobromic acids.

The water of the Dead Sea has a far stronger saline impregnation than sea-water, containing one-fourth of its weight of solid matter. It has a peculiarly bitter, saline, and pungent taste, and its specific gravity is 1.211. According to the analysis of Marcet, 100 parts of it are composed of hydrochlorate of magnesia 10.246, hydrochlorate of soda 10.36, hydrochlorate of lime 3.92, and sulphate of lime 0.054. In the river Jordan, which flows into the Dead Sea, Marcet discovered the same principles as in the lake itself.

6. *Siliceous waters* are very rare, and in those hitherto discovered, the silica appears to have been dissolved by means of soda. The most remarkable of these are the boiling springs of the Geyser and Rykum, in Iceland.

It is remarkable that nitrogen gas very generally occurs in hot springs. ts probable sourse is clearly referrible to atmospheric air contained in water, which air has been deprived of its oxygen by chemical changes in the interior of the earth.

SECTION IV.

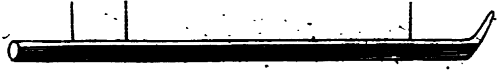
ORGANIC ANALYSIS.

The exact analysis of organic bodies is one of the most delicate operations in which the analytical chemist is required to engage.

The chief constituents of organic matter being carbon, hydrogen, oxygen, and nitrogen, (896), our remarks on this subject will be limited to a general description of the methods adopted for the separation and determination of these substances. The general principle upon which the process is conducted, consists in supplying oxygen so abundantly to the organic substance, that all its carbon shall be converted into carbonic acid, and all its hydrogen into water; and so regulating the supply of oxygen that the decomposition shall be progressive, and admit of the products being collected with accuracy. The nitrogen is always determined by an independent operation, in which the other elements are neglected; and when the compound contains oxygen, its quantity is usually determined by substracting the weight of all the other constituents from that of the substance employed. For the analysis of organic substances, there are, therefore, two processes; the first to determine the quantity of carbon and hydrogen, and the second to determine the amount of nitrogen.

The substance generally used to supply the oxygen is the black oxide of copper, which is prepared by gently igniting the nitrate. Sometimes chromate of lead is employed.

Fig. 94.



A proper recipient for the materials is made by drawing out a little, and bending as in figure 94, a straight tube of green or other hard glass, about 16 inches long, and ¼ or ½ an inch in diameter. The extreme point of the tube being closed, a little finely powdered oxide of copper is introduced, so as to occupy about 2 inches of the tube, and then enough of the substance to be analyzed, intimately mixed with oxide of copper, to fill about 6 inches more; and last of all should be several inches of the pure oxide of copper, care being taken that every particle of the organic substance weighed is mixed with the oxide. The dotted lines show the several divisions, the space to the left of the last being vacant, which should not exceed two or three inches. Means now must be taken to remove all moisture that may have found its way within; and during the whole operation, great care must be taken to prevent the accession of moisture, which is readily absorbed by oxide of copper, and would of course give a fallacious result. The particular means by which this object is accomplished, it is not necessary here to describe further. Next two tubes are to be provided, one to contain dry chloride of calcium to absorb the water which is formed, and the other, which is usually made of a peculiar construction, to contain a solution of caustic potassa, for absorbing the carbonic acid. The tube containing the chloride of calcium is first attached to the combustion tube, and to this is connected the potassa tube, so that the carbonic acid before being absorbed by the potassa, is thoroughly deprived of its moisture by passing over the chloride of calcium.

Having all things in readiness, pieces of ignited charcoal are to be applied to the part of the tube containing the pure oxide of copper last introduced, and the heat is gradually to be extended towards the other extremity until the whole is at a red heat. As a little carbonic acid and watery vapor will still remain in the tube, the extreme point of the sealed end is now broken off, and a current of air is gently sucked in by means of a tube attached to the other extremity of the apparatus; and they are thus brought in contact with the substances placed to absorb them. The apparatus is then taken asunder, and the potassa and the chloride of calcium, still remaining in the tubes, carefully weighed; the increase of course gives the weight of the carbonic acid and the water formed during the operation. From these data very simple calculations will show the quantities of carbon and hydrogen in the substance operated upon.

In some cases, in addition to the above, a current of pure oxygen is passed over the materials at the close of the operation, to insure the combustion of all the carbon.

If the substance to be analyzed is liquid and volatile, it is introduced into the tube in small glass bulbs, and the heat applied so as to volatilize it only after the oxide of copper is fully heated, or a portion of it. Many precautions are necessary in the analysis both of volatile and solid substances, which cannot be here detailed.

To determine the quantity of nitrogen in an organic substance, a combustion tube, some 2 or 2½ feet long, and perfectly straight throughout, is employed. In this tube next the closed end is placed carbonate of copper, then pure oxide of copper, then oxide of copper mixed with the substance to be analyzed, then pure oxide again, and last of all some clean metallic copper, in a finely divided state. The apparatus being then connected with the pneumatic trough, ignited charcoal is applied to the closed end of the tube containing the carbonate of copper, and the carbonic acid evolved expels all the atmospheric air from the apparatus. This of course is necessary in order that the result may be accurate, the air itself containing nitrogen.

The fire is now to be withdrawn from the closed end of the tube, and applied to the part containing the metallic copper; and when this is red-hot, the combustion is carried backward, just as in the former case, till all parts of the tube are successively heated. Last of all the heat is again applied to the part occupied by the carbonate, a portion of which is supposed to remain undecomposed; and the carbonic acid liberated, expels all the nitrogen from the apparatus. The mixed gases thus produced are collected in a bell-glass receiver, and agitated with a strong solution of caustic potassa, by which the carbonic acid is absorbed and the nitrogen left in a state of purity, except that a little watery vapor will be present, for which the necessary correction can readily be applied after measuring; or it may be removed before measuring by chloride of calcium.

The use of the metallic copper in front of the mixture is to decompose any nitric oxide which may be formed during the combustion in the tube and which would falsify the result if it were not decomposed.

When the organic substance to be analyzed contains chlorine, sulphur arsenic, &c., it must first be destroyed by nitric acid, or by ignition with potassa or lime, and the organic constituents then determined in the ordinary way. In organic salts, the metallic basis is determined by igniting the substance, burning away the organic element, and determining the quantity of inorganic base, by whatever method is best suited to its individual nature.

APPENDIX.

TABLES OF WEIGHTS AND MEASURES.

WEIGHTS.

[illegible] Standard Troy Weight.

[illegible] = [illegible] Pennyweight

[illegible] = [illegible] = [illegible] Grains

[illegible] = [illegible] Grains

[illegible]

[illegible] = [illegible] Grains

[illegible] = [illegible] Grains

[illegible]

[illegible] Grains (Troy)

[illegible]

[illegible] Grains

[illegible]

[illegible] weight

[illegible]

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APPENDIX.

TABLES OF WEIGHTS AND MEASURES.

WEIGHTS.

English Imperial Standard Troy Weight.

24 Grains = 1 Pennyweight
20 Pennyweights = 1 Ounce = 480 Grains.
12 Ounces = 1 Pound = 5760 Grains.

Avoirdupois Weight.

1 Drachm = 27.34 Grains (Troy).
16 Drachms = 1 Ounce = 437.5 Grains.
16 Ounces = 1 Pound = 7000 Grains.
28 Pounds = 1 Quarter.
4 Quarters = 1 Cwt. or 112 lbs.
20 Cwt. = 1 Ton.

Apothecaries' Weight.

20 Grains = 1 Scruple ℈.
3 Scruples = 1 Drachm ʒ.
8 Drachms = 1 Ounce ℥.
12 Ounces = 1 Pound = 5760 Grains, (Troy.)

French Decimal Weights.

Gramme = 15.4063 Troy Grains.
Decigramme = 1.5406 do.
Centigramme = 0.1540 do.
Milligramme = 0.0154 do.

MEASURES.

Wine or Apothecaries' Measure.

60 Drops = 1 Drachm ʒ.
8 Drachms = 1 Ounce ℥.
16 Ounces = 1 Pint.
8 Pints = 1 Gallon = 231 Cubic Inches.

The English Imperial Gallon contains ten pounds Avoirdupois weight of distilled water, or 277.458 Cubic Inches.

French Decimal Measure.

Litre = 61.02525 Cubic Inches.
Decilitre = 6.10252 do.
Centilitre = 0.61025 do.
Millilitre = 0.06102 do.

The French Litre is a little more than the English Quart Wine Measure.

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THE END.

QUESTIONS

TO

JOHNSTON'S CHEMISTRY.

Most of the questions have reference to the part of the work in large type; the few, the answers to which are found in the part in small type, are printed in italics.

INTRODUCTION.

PAGE 11. Into what three branches may the science of nature be divided?
What three sciences are included in the first branch?
Of what does Natural Philosophy teach?
How may chemistry be defined?
To what has the name atom or molecule been applied?
What two kinds of atoms are there?
P. 12. What are integrant particles or atoms?
What are constituent atoms?
Into what two classes may all bodies be divided?
What is a simple body?
What is a compound body?
How many simple bodies are known?
What is *cohesion*?
What is affinity?
Are the forces of cohesion and affinity exerted at sensible or insensible distances?
P. 13. Is matter destructible?
To what is the power of the chemist limited?
By what two methods may the composition of a body be determined?
What is meant by analysis? What by synthesis?
Into how many parts is this work divided?
What does the first part comprehend?
P. 14. Of what does the second part treat?
How are elementary bodies divided?
What does the third part treat of?
What is included in the fourth part?

PART I.

IMPONDERABLE SUBSTANCES.

PAGE 15. What is meant by the term *heat*?
How is the word *caloric* used?
Why is heat said to be imponderable?
How is heat known to be present in all bodies?
P. 16. How is it shown that heat may be transferred from one substance to another?

By what way is heat communicated from a hot body to one which is colder?

When is heat said to be communicated by *radiation*?

When two bodies of different temperatures are in contact, what are the principal conditions that influence the communication of heat from one to the other?

P. 17. What is meant by the conduction of heat?

Why, on a cold morning, do some substances feel colder than others, though all have been exposed to the same atmosphere?

What is meant by a *conductor* of heat? What by a *non-conductor*?

How is the conducting power of solids determined?

P. 18. What metal is the best conductor?

Do all experiments bearing on this subject agree?

Why will not a handkerchief, held against the smooth back of a watch, and then brought in contact with ignited charcoal, take fire readily?

P. 19. Has the cause of the different conducting power of substances been fully determined?

Does this property seem to be intimately connected with any other property?

What is supposed to occasion the non-conducting power of cotton, wool, fur, &c.?

What is the use of fire-brick in furnaces?

Why are double windows sometimes used?

How are ice-houses constructed?

What is the design of clothing?

Is the general practice of mankind in their selection of clothing justified by experiment?

P. 20. What effect does snow have upon the earth in winter?

How is advantage taken of the conducting power of substances in the construction of lamps?

How is heat distributed through liquids?

Why is motion produced among the particles of a liquid by applying heat?

What is meant by the *convection* of heat?

Can a liquid be heated by applying heat at its surface?

P. 21. *How may the establishment of the currents in a liquid by heat be shown?*

How may water be made to boil in a vessel, and yet contain ice at the same time?

P. 22. When is heat said to be *radiated*?

When a heated body is suspended in the air, by what three ways is its temperature reduced?

In what direction is heat emitted from the radiating surface?

When rays of heat fall upon a surface, in what three ways may they be disposed of?

What is the chief circumstance that influences the radiation of heat from a body?

What surfaces radiate most freely?

How is the radiating power of polished surface affected by scratching it?

P. 23. Does the radiating power of a body depend entirely upon the condition of its surface?

What substance forms the best radiating surface?

Does the color of a body appear to have any influence upon its radiating power?

What kind of vessels retain heat best?

P. 24. Why should stoves and stove-pipes be made of a material having a dark rough surface?

How may the reflection of heat be shown?

What are the angles of *incidence* and *reflection?*

P. 25. May heat, unaccompanied by light, be radiated and reflected?

What is meant by the *absorption* of heat?

When a ray of heat impinges upon a body, in what three ways may it be disposed of?

Is the absorptive power affected by the nature of the surface?

How do those qualities of a surface which increase reflection affect absorption?

Into what two classes may surfaces be divided, with reference to their power of transmitting heat?

P. 26. Does radiated heat pass through a vacuum?

What effect has the air upon the transmission of radiant heat?

Do transparent media affect the free transmission of heat?

P. 27. When is a body said to be *transcalent* or *diathermanous?*

Are transcalent bodies always transparent?

What is the most transcalent substance known?

What two theories of radiation have been proposed?

Which theory is most generally adopted?

On the theory of Prevost, when does the temperature of a body fall? And when does it become warmer?

P. 28. What is *dew?*

When does the most copious deposition of dew take place?

Why does the surface of the ground become colder than the surrounding atmosphere, in a calm star-light night?

Why is not the same effect produced when it is cloudy?

P. 29. Why is dew deposited upon such substances as grass, wood, the leaves of plants, &c., while other bodies, as smooth stones, remain perfectly dry?

By what means is artificial ice formed in some parts of India?

At what time is the congelation greatest?

What is meant by the *dew-point?*

How would you explain the deposition of dew upon a pitcher filled with recently drawn spring-water in summer?

P. 30. What effect does heat produce upon the dimensions of bodies?

How is the form of a body dependent on heat?

When is a body said to be *incandescent?*

Are chemical changes influenced by heat?

Under what three heads will the effects of heat be further discussed?

How are the integrant molecules of a body influenced by heat?

What force must be overcome, in order that expansion may ensue?

In what bodies should heat produce the greatest expansion?

P. 31. Are all bodies expanded by heat?

Is this expansion increased or diminished by increase of temperature?

Do, or do not, different bodies expand equally when equally heated?

P. 32. How is advantage taken of the expansion of iron by heat in the tiring of wheels?

How are clocks affected by the expansion and contraction of their pendulums in summer and winter?

Why are brittle substances broken when unequally heated?

How may the expansion of a liquid be shown?

P. 33. Do all liquids expand equally by an equal increase of temperature?

Do liquids expand more or less at high temperatures than at low, for equal increments of heat?

What peculiarity in the effect of heat upon some bodies is mentioned?

How does the specific gravity of ice compare with that of water?

Is it merely in the act of freezing that water expands?

How may the expansion of water by freezing be shown?

P. 34. *At what temperature is water most dense?*

What is the explanation given of the expansion of water in freezing?

What is ground or anchor ice, and what is the explanation of its formation?

What other substances besides water expand on solidifying?

P. 35. What would be the effect upon large bodies of water, if its density continued to increase as it froze, as is the case with mercury and many other substances?

Why does ice float upon the surface of water?

How much does the volume of a gas at 32° expand for every degree it is heated?

What is the design of the *thermometer?*

Who first constructed a thermometer?

How was the thermometer of Sanctorio constructed?

What are the objections to the use of this thermometer?

P. 36. How is the *Differential thermometer* constructed?

Will this thermometer indicate changes of temperature in the atmosphere?

What use is made of it?

What was the peculiarity of Howard's thermometer?

P. 37. Do solids answer well for constructing thermometers?

What are some of the properties required in a substance for forming a good thermometer?

What substance fulfils these conditions better than any other?

Are its expansions for a given increase of temperature the same at all temperatures?

How is the common thermometer constructed?

P. 38. What thermometer is chiefly used in this country and in England?

Where is the zero on this thermometer?

How many degrees are there between the freezing and the boiling points?

What are the peculiarities of the centigrade thermometer, and that of Reaumur?

How are degrees below zero usually designated?

Can the mercurial thermometer be used to measure temperatures below the freezing point of mercury?

What thermometer is made use of for this purpose?

Can the indications of the mercurial thermometer for temperatures above 212° be fully relied upon?

P. 39. What is the design of the *Register thermometer?*

How is it constructed?

What is the *pyrometer?*

Upon what does the action of most pyrometers depend?

P. 40. In what three states does matter exist?

Upon what does the form any body assumes depend?

To what is the property of repulsion owing?

How may the form of a body be made to vary at pleasure?

What is meant by the melting point of a body? What by the freezing point?

If a pound of water at 32° is mixed with another pound at 172°, what will be the temperature of the mixture?

But if a pound of ice at 32° is mixed with a pound of water at 172°, what will be the resulting temperature?

P. 41. How many degrees of heat are absorbed by water as it forms from ice?

What is meant by the *heat of fluidity?*

Is the heat of fluidity the same in different substances?

How is liquefaction generally produced?

How is liquefaction produced in freezing mixtures?

What is said of the cold produced by a mixture of snow and chloride of calcium?

Is heat always absorbed during the solution of a salt?

P. 42. What effect is produced upon the temperature when liquids congeal?

How low may water be cooled without freezing?

How is a thermometer placed in it affected when freezing commences?

In what two states on the theory of Black does heat exist?

When a solid becomes liquid, what is supposed to become of its free caloric?

What is the greatest cold that has been produced by freezing mixtures?

How great a cold has been produced by means of solid carbonic acid? (See 81).

Has the absolute zero been determined?

P. 43. Into what two classes are aeriform substances divided?

What is the distinction between them?

What is the cause of vaporization?

When is a substance said to be *fixed* in the fire?

Are liquids or solids the more readily converted into vapors?

Do vapors occupy more or less space than the solids or liquids from which they are formed?

How many times its volume does water expand in changing into steam?

How are *Ebullition* and *Evaporation* distinguished?

P. 44. What is meant by the *boiling point* of a liquid?

At what temperatures do alcohol, water and ether boil?

What is the temperature of boiling mercury?

Is the boiling point of a substance constant?

What circumstance essentially affects the boiling point of liquids?

What is the pressure of the atmosphere upon every square inch of surface?

Why does water boil at a lower temperature on a mountain than in a valley?

If the pressure of the atmosphere were removed entirely, how would it affect the boiling point of liquids?

P. 45. Is a liquid always hot when it boils?

Why cannot water be heated in the open air above 212°?

May it be heated above 212° when confined?

What is the tension of steam arising from water heated to 250°?

On what two properties of steam does its application in working the steam engine depend?

P. 46. Is the formation of vapor attended by the absorption of heat?

How much heat is given out when steam at 212° is converted into water at 212°?

In what does *distillation* consist?

P. 47. When is the term *condensation* used? When the term *sublimation*?

What is meant by *evaporation*?

Do all liquids evaporate with equal rapidity?

What are the chief circumstances that influence evaporation?

P. 48. How may it be shown that caloric is absorbed during the evaporation of a liquid?

How may water be frozen by its own evaporation under the receiver of the air-pump?

On what principle is the water frozen in the cryophorus?

P. 49. How is the temperature of the human system prevented from rising too high in warm weather?

To how high temperatures have individuals voluntarily exposed themselves without injury?

How is the high temperature of summer mitigated?

Why are porous earthen vessels sometimes chosen to contain water for drinking in warm weather?

P. 50. What was formerly supposed to be the cause of the evaporation of water in the air?

What is the true cause of evaporation?

What constitutes the mists and clouds which are constantly seen in the atmosphere?

P. 51. How is it that all the water on the surface of the earth is constantly subjected to a natural distillation?

What may the gases be considered?

Why are these substances always found in the gaseous state?

What is the usual method of liquefying a gas?

What is the only gas that has been solidified?

What is the method of solidifying carbonic acid gas?

P. 52. What is the appearance of frozen carbonic acid?

P. 54. Does the thermometer indicate the quantity of heat in a body?

Does equality of temperature in two bodies necessarily imply that they contain the same amount of heat?

If a pound of mercury at 160° is mixed with a pound of water at 40°, what will be the temperature of the mixture?

If the water is at 160° and the mercury at 40°, what will be the resulting temperature?

If a given amount of heat raises the temperature of water 5 degrees, how high will it heat an equal weight of mercury?

P. 55. If equal quantities of heat are added to equal weights of water, spermaceti oil, and mercury, what will be their relative temperatures?

What is meant by the *specific heat* of a body?

P. 56. Is the specific heat of all bodies the same?

Is the specific heat of a body greatest when in the solid or liquid state?

How is a thermometer affected when placed under the receiver of the air-pump and the air exhausted?

What is the principle upon which the fire-syringe operates?

Why is a piece of metal heated by hammering?

P. 57. What are some of the principal sources of heat?

What is the great source of heat to the earth?

How may the heat of the sun be greatly concentrated?

How is artificial heat generally produced?

What is said of the heat produced by the boring of cannon?

P. 58. What two theories of light have been proposed?

What was Newton's theory?

What is the undulatory theory?

Which is now most generally received?

P. 59. From what points in a luminous body does light emanate?

What is meant by a *ray* of light?

In what direction does light always move unless turned out of its course?

Is the passage of light instantaneous or progressive?

When is light said to be *reflected?*

What kind of surfaces reflect light most perfectly?

P. 60. What two laws govern the reflection of light?

When is light said to be *refracted?*

P. 61. Is there any difference in the power of bodies to refract light?

What class of bodies refract light most powerfully?

What two laws govern the refraction of light?

P. 62. What is meant by the *index of refraction?*

What is meant by double refraction?

P. 63. How may the analysis of light be effected?

How did Newton decompose light?

What is the *solar spectrum?*

What is the most convenient instrument for decomposing light?

P. 64. What occasions one of the greatest difficulties in the manufacture of telescopes?

What is meant by an *achromatic* optical instrument?

How are the different colors of bodies explained?

What are the three primary colors, according to Brewster?

In what part of the spectrum is the maximum illumination?

Does the solar ray contain heat as well as light?

P. 65. Is the solar ray capable of producing chemical changes?

What effect is produced by light upon the white chloride of silver?

Is it supposed the rays which produce the chemical changes are separate from the heating and colorific rays?

P. 66. What is *Photography*?

How are pictures formed on paper by means of chloride of silver?

What is the *Daguerreotype*?

What are the essential parts of the Daguerreotype process?

P. 67. Does terrestrial light differ essentially from solar light?

When is a body said to be *incandescent*?

At what temperature does a heated body become luminous in the dark?

Do the various kinds of artificial light differ in the appearances presented when transmitted through the prism?

P. 68. How is lime made to emit a dazzling light?

What is meant by the phosphorescence of a body?

P. 69. *What is the design of the photometer?*

P. 70. What effect is produced upon some bodies, as glass, sealing-wax, and sulphur, by being rubbed?

What is the derivation of the word *electricity*?

When is a body said to be electrically excited?

P. 71. When an electrified body touches one that is not electrified, what is the effect produced?

What are *conductors* and *non-conductors* of electricity?

What are some of the bodies belonging to each class?

P. 72. When is a body said to be insulated?

Why are electrical experiments apt to fail in damp weather?

What terms are used to designate the different kinds of electricity developed upon sealing-wax and upon glass?

P. 73. Are both electricities always excited by friction?

Why are not both collected?

When sealing-wax is rubbed with brown paper, which will be positive and which negative?

What is the state of glass when rubbed?

Is it known whether electricity is really a material agent?

What is Dufay's theory of electricity?

P. 74. When, on this theory, is a body in its natural state?

What is Franklin's theory?

On this theory, when is a body in a state of excitement?

When do bodies attract, and when repel each other?

P. 75. What is the design of the electrical machine?

What are some of its principal parts?

To what is the electricity excited by the machine to be attributed?

P. 76. Can any quantity of electricity be obtained, when the rubber and he prime conductor are both insulated?

How is electricity excited in the metals by change of temperature?

What is the thermo-multiplier?

P. 77. What is said of chemical action as a source of electricity?

P. 78. May electricity be developed by change of form in a body?

P. 79. When is a body said to be electrified by *induction*?

P. 80. How is the Leyden jar constructed?

How is the electric shock produced by means of the jar?

To whom is the science of Galvanism indebted for its origin and its name?

What was the discovery made by Galvani?

P. 81. To what did Volta attribute the electricity excited?

Are common electricity and galvanism attributed to the same agent?

Of what does a *simple galvanic circle* consist?

P. 82. When is the circle said to be *closed*?

P. 83. What is the direction of the positive current?

How may a simple galvanic circle be formed of one metal and two liquids?

P. 85. Is it necessary that zinc and copper should always be used?

Must the liquid always contain an acid?

Under what circumstances is the galvanic action most intense?

How is the rapidity with which the metals are acted on by the solution, affected by the galvanic current which is excited?

What is galvanized iron?

P. 86. Are metallic bodies essential to the production of galvanic phenomena?

Of what does the *galvanic battery* consist?

How is the *Voltaic pile* constructed?

P. 87. What is meant by the *poles* or *electrodes*?

P. 88. What is the peculiarity of the *galvanic deflagrator*?

What is the peculiar construction of the *calorimotor*?

P. 89. Does the energy of the battery depend in any degree upon the nature of the liquid used?

What liquid answers best for general purposes?

P. 90. What is meant by the intensity of an electric current?

Upon what may we suppose it to depend?

What kind of conductors do large quantities require?

What is said of the intensity of the current from a single pair of plates?

What kind of circle gives a current of the highest intensity?

P. 91. Into what three classes may the effects of galvanism be divided?

Do the electrical effects depend most upon intensity or upon quantity?

What is the effect of sending the current through charcoal?

P. 92. What was the first chemical effect of galvanism discovered?

At which wire is the oxygen collected, when water is decomposed?

Why is it necessary to use gold or platinum wires?

May salts be decomposed in a similar manner?

What are *electro-negative* and *electro-positive* substances?

P. 93. How, in decomposing a salt, may the acid be collected in one cup and the base in another?

What are meant by *anode* and *cathode*?

P. 94. What is it *to electrolyze* a compound?

What are *anions* and *cations*?

Are all compounds *electrolytes*?

P. 95. What is *loadstone*?

What are the *poles* of a magnet?

P. 96. If a magnet is suspended in a horizontal position, in what direction will it settle?

When do two magnets attract each other, and when do they repel?

What is the effect upon a piece of soft iron, when brought in the vicinity of a magnet?

What is an artificial magnet?

P. 97. What is the *armature* or *keeper*?

What is the *magnetic needle*?

How is the *dipping needle* constructed?

What may the earth be considered, in reference to magnetism?

What effect has lightning long been known sometimes to produce upon the magnetic needle?

P. 98. What was Oersted's discovery, that has laid the foundation for the science of electro-magnetism?

What is the method suggested by Ampère for remembering the direction of the movements?

When the influence of the earth's magnetism is neutralized, what position will the needle take with reference to the wire?

Is the conducting wire capable of attracting and repelling the magnet?

P. 99. Do the poles tend to revolve around the wire?

If we suppose the conducting wire to be in a vertical position, and the positive current descending, in which direction will the north pole of a magnet in the vicinity of the wire tend to revolve?

P. 100. Are the phenomena of electro-dynamics produced by accumulated electricity, or by electricity in motion?

What is the best form of a battery for producing the magnetic effects?

What is the *galvanometer* or *galvanic multiplier*?

P. 101. How does the influence of a single point of the conducting wire upon the needle, vary with the distance?

P. 102. How is De la Rive's ring constructed?

How will it arrange itself when free to move?

What may we therefore regard it?

P. 103. How may magnetism be induced in pieces of soft iron by means of the galvanic current?

How may a piece of soft iron in the form of a horse-shoe be magnetized?

P. 104. In order to develope magnetism the most freely, should the wire be in a single piece or in several pieces?

What is the *electro-magnetic engine*?

P. 105. What is Ampère's theory of magnetism?

If we suppose the magnet to be a straight bar, and to stand on its north pole, in what direction does the positive current move in the south pole, standing upward?

P. 106. *How are electric currents supposed to move in the earth?*

Does a current passing through a helix, excite a current in another helix coiled around it?

P. 107. What is *magneto-electricity*?

How is electricity excited by magnetism?

P. 109. What was the theory of galvanism proposed by Volta?

P. 110. Who proposed the chemical theory?

What is the chemical theory?

What was Davy's theory?

P. 111. Which of these theories is now generally received?

May a spark sometimes be obtained before the contact of the metals?

PART II.

INORGANIC CHEMISTRY.

PAGE 113. What is meant by the specific gravity of a body?

How is it found?

P. 114. How is the hydrometer constructed?

How is the specific gravity of a solid found?

For what is Nicholson's areometer used?

P. 115. What substance is taken for the standard, in determining the specific gravity of the gases?

P. 116. What suggested the name of *oxygen*?

What is an oxide?

How are the different acids of the same substance designated?

How are acids named that contain no oxygen?

When is the termination *uret* used?

P. 117. How are the different oxides of the same substance designated?

Is the termination *uret* as much used as formerly?

What is a *salt*?

How do we distinguish the salts of the different acids?

What are *neutral*, *sub*, and *super* salts?

P. 118. What numerals are used when the acid is in excess?

What are used when the base is in excess?

What are acid and basic salts?

What is meant by the terms monobasic, bibasic, &c.?

To what are all chemical phenomena owing?

P. 119. At what distances is this force exerted?

What simple instances of the exercise of affinity are mentioned?

Why does not sugar dissolve with equal facility in alcohol and water?

Why is affinity said to be elective?

What is meant by *single elective* affinity?

Why is camphor set free from its solution in alcohol by pouring in water?

P. 120. *Is chemical action to be regarded as the result of affinity alone?*

P. 121. How many compounds are destroyed, and how many new ones formed, in cases of double elective affinity?

What is meant by *quiescent* and *divellent* affinities?

P. 122. What are some of the circumstances that affect the action of affinity?

By what two methods may cohesion be diminished?

P. 123. How is chemical action affected by elasticity?

How does heat influence chemical action?

P. 125. Do any important changes take place during chemical action?

Could we judge of the composition of water, from a mere knowledge of its general properties?

Who first proved the compound nature of the alkalies?

P. 126. Is it possible to predict the properties of a compound from knowing those of its ingredients?

What effect is usually produced upon the bulk of two bodies when they combine?

What occasions the heat produced when lime is slacked?

Are the changes produced by chemical combination various?

What are some of the examples mentioned?

P. 127. Do substances combine indefinitely in all proportions?

Do water and alcohol, or water and sulphuric acid, unite in all proportions?

What is said of the solution of common salt in water?

P. 128. Do the metals combine in definite proportions?

What indications are there that in these cases there are a few definite compounds formed?

P. 129. What is the first law of combination?

What is the second law of combination?

What is adopted in this work as the unit of the system of numbers used to designate the proportions in which substances combine?

P. 130. What is meant by the *equivalent* of a substance?

How is the equivalent of a compound substance determined?

P. 131. What is the third law of combination?

P. 132. What is the fourth law of combination?

P. 135. What is the object of using chemical symbols?

From what are they derived?

P. 137. What is a *crystal*?

What are the most favorable conditions for the formation of crystals?

Is the number of forms in which a substance may crystalize limited?

P. 138. May crystaline forms serve as a ground of distinction between substances?

Does crystalization sometimes take place in solids?

Into what two classes are the forms of crystals divided?

P. 139. What is the number of primary forms?

Into what three classes may they be divided?

What are *right prisms?*

What are *oblique prisms?*

How many octohedrons are there?

P. 140. What is the form of the cube?

How is the right square prism defined?

How is the right rectangular prism described?

P. 141. What is the form of the rhombohedron?

What is the form of the right rhomboidal prism?

How is the regular octohedron described?

What is the form of the rectangular octohedron?

P. 142. How is the rhombic dodecahedron defined?

What is said of the number of the secondary forms?

How are they derived from the primary forms?

What is meant by a *tangent* plane?

P. 143. What is a *system of crystalization?*

How many systems of crystalization are there?

How many different forms of crystals of carbonate of lime are known?

When are two bodies said to be isomorphous?

Are there known many isomorphous substances?

P. 144. Do isomorphous substances generally resemble each other in their various properties?

P. 145. *When is a substance said to be dimorphous?*

By whom was oxygen discovered?

What are some of the names by which it has been known?

Why has it received its present name?

By what two methods may it be obtained from the peroxide of manganese?

P. 146. Does this substance afford the gas perfectly pure?

What is said to be the best method of preparing oxygen for ordinary purposes?

P. 147. What are the changes that occur during the formation of the gas by this process?

What are some of the properties of this substance that are mentioned?

What is the specific gravity of oxygen gas?

Is it absorbed by water?

What is said of its affinity for other simple substances?

What is an oxide?

How are the oxides divided?

What is ordinary combustion?

Do substances that burn in air, burn more freely in oxygen?

P. 148. *How are iron and steel made to burn in oxygen?*

What are the phenomena that are exhibited during the combustion of a taper in oxygen?

What are the chemical changes that take place?

Does oxygen always disappear during combustion?

Does the product of the combustion weigh more or less than the combustible body consumed?

Are the wood and other substances consumed in fires destroyed?

P. 149. Is oxygen necessary to support respiration?

What will be the effect if a bird, or other small animal, is confined in a mited portion of atmospheric air?

Will a lighted taper continue to burn in an atmosphere that will not support respiration?

What is the effect of breathing pure oxygen gas?
What does the term *combustion* imply in its common signification?
May other substances besides oxygen support combustion?
P. 150. What may combustion be considered?
To what did Stahl attribute the combustibility of bodies?
What, on the Stahlian theory, was a metallic oxide considered?
On this theory, should the product of combustion weigh more or less than the combustible body consumed?
What was hydrogen formerly called?
Why is it called hydrogen?
P. 151. What two methods are given for procuring hydrogen?
Which method is most convenient?
Does this method afford perfectly pure hydrogen?
What are some of the properties of this substance that are mentioned?
P. 152. What is its specific gravity?
What is the weight of 100 cubic inches?
Does it support respiration?
Does it support combustion?
What is said of its combustibleness?
Why, in the experiment with the candle, does the gas burn only at the surface?
What effect is produced by flame on a mixture of this substance and atmospheric air?
Do oxygen and hydrogen gases combine at ordinary temperatures?
How may a mixture of the two gases be inflamed?
What is the effect of spongy platinum?
P. 153. How are musical sounds produced by a jet of hydrogen?
What is said of the heat produced by the combustion of hydrogen?
How are oxygen and hydrogen burned so as to produce great heat?
What is the danger of mixing the gases before they are consumed?
P. 154. How many compounds of hydrogen and oxygen are there?
What is the sole product of the combustion of hydrogen?
How has the composition of water been demonstrated?
P. 155. What is the quantity of oxygen and of hydrogen in 100 parts of water?
What is the explanation of the process of procuring hydrogen by the action of diluted sulphuric acid upon zinc?
What are some of the properties of water that are mentioned?
What are the compounds of water called?
P. 156. For what purpose is the adjunct *hydro* used?
What is the source of the purest natural water?
What gas is contained in rain and snow water?
What is the source of the impurities contained in well and spring water?
How may water be obtained absolutely pure?
What is the composition of peroxide of hydrogen?
P. 157. Who first determined the existence of nitrogen as a separate substance?
Why was it once called *azote*?
How is nitrogen gas most conveniently obtained?
Is this gas sometimes found in the water of mineral springs?
What are some of the properties of nitrogen?
Will it support combustion or respiration?
P. 158. What is its specific gravity?
Is it a simple substance?
How many compounds of nitrogen and oxygen are there besides atmospheric air?
Where is atmospheric air found?
How many times is atmospheric air lighter than water?

What is the weight of 100 cubic inches?

Who first noticed the pressure of the atmosphere?

What is the amount of the atmospheric pressure at the surface of the sea for every square inch?

How high will it support a column of water?

P. 159. Is this pressure variable?

How is it affected by elevation above the surface of the sea?

Is the pressure of the air constant at the same place?

How is a given volume of air affected by pressure?

Where is the atmosphere most dense?

To what height does the atmosphere extend?

P. 160. What is the best method to determine the relative proportion of oxygen in the atmosphere?

What is the proportion of oxygen and nitrogen found to be?

Is the proportion uniform?

What other gases are always found present?

Is the proportion of carbonic acid gas always the same?

P. 161. What is the medium quantity of 10,000 parts of air?

To what are the chief chemical properties of air owing?

Is the use of the nitrogen fully known?

P. 162. What is the composition of protoxide of nitrogen?

How is it prepared?

What are the chemical changes that take place?

Does this gas support combustion?

P. 163. What is its specific gravity?

Does it support respiration?

What effect does it produce when breathed?

What is the binoxide of nitrogen?

What has it been called?

By what means is it prepared?

P. 164. What are some of its properties?

What effects are produced when it is mixed with atmospheric air?

Are any substances capable of burning in it?

Can it be breathed?

What is its specific gravity?

What is the composition of hyponitrous acid?

P. 165. *What is the composition of nitrous acid?*

May nitric acid be formed by the direct union of its elements?

Can it exist in an insulated state?

P. 166. What is the common name for ordinary liquid nitric acid?

How is the nitric acid of commerce prepared?

Is the acid thus formed pure?

To what is the yellow color of ordinary nitric acid owing?

How may the nitrous acid be expelled?

P. 167. What is the specific gravity of the strongest nitric acid?

Under what circumstances may the strength of nitric acid be increased by boiling?

What two varieties of nitric acid are known in commerce?

At what temperatnre does the strongest nitric acid freeze?

How are most of the metals acted on by this acid?

What effect is produced if it is flung on burning charcoal?

What effect is produced by it on powdered charcoal and oil of turpentine?

P. 168. How does it affect vegetable substances?

How does it affect the nails and skin?

How may gold-leaf be made use of as a test for nitric acid?

What use is made of it in the arts?

What is the only compound of nitrogen and hydrogen?

By what other names has ammonia been known?

P. 169. What is the most convenient method of obtaining gaseous ammonia?
What salt is sometimes found in rain-water after a thunder storm?
How is its existence here accounted for?
How may an abundant supply of the gas be obtained?
What is said of the odor of ammonia?
May it be inflamed?
What pressure is required to condense it into a liquid?
Why is it called volatile alkali?
Have we synthetic proof of the composition of ammonia?
How has it been analyzed?
P. 170. What is its specific gravity?
What is said of its affinity for water?
What is the common *liquid ammonia*?
How many times its own volume will water absorb?
At what temperature does it freeze?
How may a vessel be readily filled with the gas?
What is said of the general distribution of carbon?
In what is carbon found in a state of purity?
How is common *charcoal* prepared?
What is *coke*?
What is *ivory black*? Lampblack?
What is said of the hardness of the diamond?
What is its specific gravity?
Who first supposed it to be combustible?
How was the fact afterwards proved?
How is the diamond known to be crystalized carbon?
What are some of the properties of charcoal?
What is said of its power of absorbing the gases?
Can it be affected by heat if oxygen is not admitted into contact with it?
P. 172. Why does recently burned charcoal become heavier by standing in the air?
What is said of its power of absorbing the odoriferous particles of bodies?
Is charcoal combustible?
Why does it not take fire spontaneously in the open air?
What is the product of its combustion?
What is *graphite* or *plumbago*?
What use is made of carbon?
P. 173. How many compounds of carbon and oxygen are known?
How may protoxide of carbon be prepared?
What are some of the properties of carbonic oxide?
Will it support respiration or combustion?
What was carbonic acid gas formerly called?
From what was it obtained by Dr. Black?
How is it most conveniently prepared?
P. 174. What is its specific gravity?
Does it support combustion or respiration?
How is a lighted candle affected when plunged into an atmosphere containing a large quantity of this gas?
How does it operate on the system when breathed?
How is lime-water affected by it?
P. 175. What is said of its absorption by water?
How is the quantity absorbed affected by increasing the pressure?
How are soda fountains constructed?
What occasions the effervescence which is observed on opening bottles of beer, cider, champaigne, &c.?
How may water be deprived of its carbonic acid?
Is it always found in the atmosphere?

What is it sometimes called when collected in quantities in coal mines?

P. 176. What is said of the number of compounds of carbon and hydrogen which are known?

What two only will be described?

In what situations is light carburetted hydrogen found?

What are some of its properties?

P. 177. Is it inflammable?

What is its specific gravity?

What is it called when collected in large quantities in coal mines?

What is the danger occasioned by such collections of the gas?

What is the design of the *safety lamp?*

Can flame pass through wire gauze?

P. 178. How is the safety lamp constructed?

Can the workmen continue to use this lamp in an explosive mixture of the gas?

P. 179. Who discovered olefiant gas?

Why did it receive this name?

How may it be conveniently prepared?

What is its specific gravity?

What is said of the action of chlorine upon it?

How is it affected by having a succession of electric sparks passed through it?

P. 180. What is the composition of cyanogen?

How is cyanogen prepared?

What is said of its color and odor?

Does it support combustion?

What is said of its tendency to unite with elementary substances?

P. 181. In what situations is sulphur usually found?

What is its appearance?

What are some of its other properties?

How is it affected by heat?

How may it be crystalized?

At what temperature is it volatilized?

P. 182. What are *flowers of sulphur?*

Is sulphur soluble in water?

How may it be dissolved in alcohol?

At what temperature does sulphur inflame in the open air?

What use is made of sulphur?

How many compounds of sulphur and oxygen are there?

P. 183. Who first obtained sulphurous acid in a separate state?

How may it be prepared?

How may it be distinguished from all other gases?

How are burning bodies affected when plunged into it?

Can it be taken into the lungs?

What is said of its absorption by water?

What is said of its bleaching properties?

P. 184. Can the solution of sulphurous acid in water be preserved?

What pressure is required to convert the gas into a liquid?

What is said of the cold produced by its evaporation?

Has oil of vitriol been long known?

What is the method of preparing it at Nordhausen in Germany?

What is the composition of green vitriol?

P. 185. What is the appearance of the acid as prepared by this means?

What is its specific gravity?

How may pure anhydrous sulphuric acid be obtained from it?

What is the process of manufacturing sulphuric acid in this country and in England?

What is the density of sulphuric acid prepared in this manner?

What is said of its strength as an acid?
P. 186. What is said of its affinity for water?
How is their temperature affected by their being mixed?
At what temperature does it freeze?
What substance is used as a test for this acid?
P. 187. What use is made of it?
In how many proportions do sulphur and hydrogen combine?
What is the common method of preparing hydro-sulphuric acid?
What are the chemical changes that occur during its formation?
How may sulphuret of iron be prepared for this purpose?
What are some of its properties?
P. 188. What amount of pressure is required to compress it into a liquid?
What is its effect upon animals, when breathed?
Does it support combustion?
What is said of its absorption by water?
What constitutes the water of sulphur springs?
Can water impregnated with this gas be kept in the open air?
What is the effect of chlorine upon the gas?
What tests of this substance are mentioned?
P. 189. What is the composition of the bisulphuret of carbon?
How may it be formed?
What is said of its refractive power?
What is said of the cold produced by its evaporation?
What has it been called?
P. 190. From what circumstance has phosphorus received its name?
From what is it prepared?
What is the process of preparing it?
P. 191. Is it obtained perfectly pure by this process?
What are the chemical changes that take place during its preparation?
What is the appearance of phosphorus?
At what temperature does it fuse?
May it be crystalized?
What is said of its inflammability?
Can it be kept in the open air?
How is it preserved?
How may the oxygen be separated from a portion of atmospheric air by means of it?
P. 192. Does it burn with brilliancy?
What use is made of phosphorus in the arts?
How many compounds of oxygen and phosphorus are there?
How is phosphoric acid formed?
P. 193. From what is phosphoric acid best prepared?
What is it called when solid?
What is said of its affinity for water?
What three *phosphates of water* are known?
What salts are formed by the monobasic phosphate of water?
What is the bibasic phosphate of water?
How may it be prepared?
P. 194. What kind of compounds does it tend to form with fixed bases?
What is tribasic phosphate of water?
How is it characterized?
What three kinds of compounds may it form with water and fixed bases?
What is phosphuretted hydrogen?
What two modes of preparing it are mentioned?
What different characteristics does it exhibit, as prepared by these two methods?
P. 195. What is now supposed to occasion this difference in its action?
What is sulphuret of phosphorus?

P. 196. How was boron first obtained by Davy?
How may it be procured for ordinary experiments?
What is its appearance?
Is it soluble in water or alcohol?
How is it affected by intense heat in close vessels?
At what temperature is it inflamed in the open air?
What is the only compound of boron and oxygen?
Where is boracic acid found as a natural product?
What is borax?
How may boracic acid be separated from it?
P. 197. Has this acid any taste?
What was silicon formerly called?
How may silicon be procured?
P. 198. What is its appearance?
How does a high temperature in close vessels affect it?
How does its specific gravity compare with that of sulphuric acid?
What is silicic acid?
Of what is it the chief ingredient?
What is the appearance of pure silicic acid?
How may it be made to unite with water?
P. 199. Has it any action on test paper?
How may *soluble glass*, or *liquor silicum*, be prepared?
What is glass?
What substances are used in its manufacture?
P. 200. In what was selenium first detected?
With what is it found combined?
What is its appearance?
Is it soluble in water?
P. 201. By whom was chlorine discovered?
What was it called?
How is it obtained?
What are the chemical changes produced?
How may it be collected?
P. 202. What is the cheapest method of preparing it?
From what does it receive its name?
What is its density?
Is it absorbed by water?
Can it be decomposed?
Does it unite with other substances?
Does it support combustion?
P. 203. What is said of its affinity for hydrogen?
Does light affect its action with other bodies?
To which pole of the battery does it go, when separated from its compounds by galvanism?
What is said of its bleaching power?
P. 204. Is water always necessary to its action?
What is said of its disinfecting power?
How may it be recognised?
In how many proportions does it combine with oxygen?
P. 205. *How is hypochlorous acid prepared?*
What was Davy's euchlorine?
How is chlorous acid formed?
P. 206. How is chloric acid formed?
What were the chlorates formerly called?
What is hydrochloric acid composed of?
P. 207. What was it once called?
How may it be conveniently prepared?
How is it obtained from sea-salt?

What is the explanation of the changes that take place?
May it be formed by the direct union of its elements?
What is the effect of the sun's rays upon a mixture of the gases?
Is any change in the volume of the gases produced by their union?
P. 208. What are some of the properties of the gas?
May it be compressed into a liquid?
What is said to be one of the most striking properties of the gaseous acid?
What occasions the dense white cloud that appears when it escapes into the air?
What is the liquid hydrochloric acid of commerce?
How many times its own volume of the gas will water absorb?
What is the ordinary method of preparing hydrochloric acid?
What is its specific gravity?
What are some of the properties of the common liquid acid?
P. 209. What are its freezing and boiling points?
What is *aqua regia?*
How may hydrochloric acid be known?
What is the composition of quadro-chloride of nitrogen?
P. 210. *For what property is this compound remarkable?*
What well-known substance does perchloride of carbon resemble?
P. 211. *What is the composition of dichloride of sulphur?*
P. 212. When, and by whom, was iodine discovered?
To what substance is it said to be analogous?
With what is it usually found combined?
What substances contain it?
How may it be detected in the sponge?
P. 213. From what is the iodine of commerce obtained?
How may the formation of iodine be illustrated?
What is the appearance of iodine?
What is its specific gravity?
What effects are produced upon it by heat?
What suggested the name iodine?
Is it a conductor of electricity?
Is it soluble in water or alcohol?
Has it an extensive range of affinity?
P. 214. Is it a simple substance?
What is its most delicate test?
Of what is iodic acid composed?
P. 215. May hydriodic acid be formed by the direct union of its elements?
What are some of its properties when in a gaseous state?
How may teriodide of nitrogen be formed?
What striking property characterizes it?
P. 216. *Do iodine and phosphorus combine readily?*
When was bromine discovered?
What is the derivation of its name?
Where is it found?
What is the usual method of preparing it?
P. 217. What is its state and appearance at ordinary temperatures?
What is its electrical state?
What are its effects upon animal life?
P. 218. Has fluorine been obtained in a separate state?
What occasions the difficulty of collecting it?
What are vessels used to contain it now made of?
What is the composition of hydro-fluoric acid?
How is it prepared?
What are the chemical changes that take place?
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How may it be preserved?

At what temperature does it boil?
What is said of its affinity for water?
What is said of its action upon glass?
How is fluosilicic acid formed?
What are some other of its properties?
P. 220. *What is fluoboric acid?*
P. 221. What is the composition of fluosilicic acid?
What are some of the properties by which the metals are distinguished?
What is said of their lustre?
P. 222. What is the number of the metals?
How many were known to the ancients?
P. 223. What is said of their specific gravity?
How is their density affected by hammering?
What is said of their malleability?
What one is most malleable?
Are they all ductile?
P. 224. Do their malleability and ductility vary with the temperature?
How is their tenacity determined?
What are some of the hardest metals?
What is meant by annealing a metal?
Are any of them crystaline in their texture?
What is the point of fusion of mercury?
P. 225. What is the point of fusion of gold?
When are the metals said to be found native?
What are *alloys*?
How is the fusibility and hardness of alloys, as compared with the ingredients of which they are formed?
How are they deflagrated?
Do they differ in the strength of their affinity for oxygen?
How are potassium and sodium affected by mere exposure to the air?
P. 226. Do any of the metals unite with oxygen in more than one proportion?
What is meant by the reduction of a metallic oxide?
What are some of the means by which these oxides are reduced?
P. 227. Do any of the metals form acids by uniting with oxygen?
What is said of the affinity of chlorine for the metals?
What are some of the properties of the metallic chlorides?
P. 228. What two views may be taken of the changes that occur when a metallic chloride is dissolved in water?
Has iodine an affinity for the metals?
P. 229. What are some of the means by which sulphurets of the metals may be formed?
P. 230. Can the sulphur be expelled by heat?
P. 231. What are the characteristics of the two classes of the metals?
What are the characteristics of the orders of Class I.?
P. 232. What are the characteristics of the orders of Class II.?
P. 233. By whom was potassium discovered?
How did he obtain it?
How is it now prepared?
What is its appearance at common temperatures?
What is its density at 60°.
P. 234. What is said of its affinity for oxygen?
How is it preserved?
What is the composition of *potash* or *potassa*?
What is its appearance?
What is hydrate of potassa?
P. 235. How is *aqua potassæ* prepared from the carbonate?
Why must the solution be filtered in a close vessel?

P. 236. How is the potassa of commerce obtained?
How may potassa in general be distinguished?
P. 237. *What is the composition of iodide of potassium?*
P. 238. By whom was sodium first obtained?
P. 239. What is the appearance of the metal?
What is its specific gravity?
What effect is produced by throwing it upon water?
What is soda composed of?
How may it be distinguished from other alkaline bases?
P. 240. What is chloride of sodium?
What are some of the varieties of this substance?
From what is it obtained?
What is said of its solubility in water?
P. 241. What use is made of this substance?
What was formerly supposed to be the composition of this substance?
Whence is chloride of sodium obtained?
What natural deposit of it occurs in this country?
From what is it manufactured in warm countries?
P. 242. *From what is lithia obtained?*
What is its metallic base?
P. 243. By what means is barium obtained from baryta?
What is its appearance?
What is baryta?
How may it be prepared from nitrate of baryta?
P. 244. What are some of its properties?
What compounds of baryta are found native?
How may baryta be distinguished from other substances?
P. 245. From what earth is strontium obtained?
P. 246. What is the composition of strontia?
Is its solution alkaline?
By what peculiarity may the compounds of strontia usually be distinguished?
P. 247. What is the composition of lime?
From what may lime of great purity be prepared?
What effect is produced upon lime by being exposed to the air?
In what consists the process of slaking lime?
What compound is formed?
P. 248. Is lime soluble in water?
Does the solution possess alkaline properties?
What use is made of lime?
What is *hydraulic* or *Roman* cement?
P. 249. How may hydraulic lime be formed from common lime?
What is said to be the most delicate test for lime?
P. 250. What is fluoride of calcium?
P. 251. How may magnesium be prepared?
What is its appearance?
What is the composition of magnesia?
P. 252. How is magnesia characterized?
How is aluminum separated from chloride of aluminum?
P. 253. Does it conduct electricity?
What is the composition of alumina?
How is pure alumina prepared?
P. 254. What are some of its properties?
How may it be recognised?
P. 256. Is manganese ever found native?
How may the metal be obtained from the oxide?
Is it fusible?

P. 257. Is the number of compounds of this metal with oxygen well settled?

How may the protoxide be formed from the other oxides?

What is its color when pure?

P. 258. How may the sesquioxide be formed artificially?

What is the black oxide of manganese?

What use is made of it in the arts?

P. 259. What other oxides is the red oxide composed of?

What two acids of manganese are known?

P. 260. What is said of the abundance and usefulness of iron?

Is it found native?

What other metal is usually combined with iron of meteoric origin?

What is an ore of iron?

How many of these are there?

What ones are chiefly used for the extraction of the metal?

P. 261. From what ores is the most of American iron obtained?

What is the process of extracting the iron?

When is sand and when lime required for the flux?

Is it cast or wrought iron that is thus obtained?

How is it converted into wrought iron?

P. 262. What is said to be the best mode of obtaining iron in a state of purity?

What is its color?

How is it welded?

What is its density?

P. 263. What occasions the rusting of iron?

Is it combustible?

What color is protoxide of iron when precipitated from its solutions by an alkali or an alkaline carbonate?

P. 264. What is the red hematite of mineralogists?

What use is made of it in the arts?

What is loadstone?

P. 265. *How many sulphurets of iron are there?*

P. 266. What are some of the carburets of iron?

May graphite be formed artificially?

Does it always contain iron?

What use is made of it?

What is the point of fusion of cast iron?

What three varieties of it are in use?

P. 267. May articles of cast be changed to malleable iron without injury?

What is *steel?*

What is *natural steel?*

How is iron changed into steel?

P. 268. How is *German steel* manufactured?

How is *cast-steel* formed?

What is the method of *case-hardening* iron?

How may steel be hardened?

How are articles of steel *tempered?*

P. 269. By what name is zinc known in commerce?

From what ores is it obtained?

Does this process produce it pure?

P. 270. What is the appearance of zinc?

At what temperature is it malleable?

What is its melting point?

What is brass?

What is *galvanized iron?*

How may protoxide of zinc be formed?

P. 271. What use has been made of it?

With what other metal is cadmium generally associated?
P. 272. What metal does it much resemble?
Is it employed in the arts?
Has tin been long known?
From what country is it chiefly obtained?
Has it been found in the United States?
P. 273. What two varieties of tin are used in the arts?
What other metal does it resemble in color and lustre?
What is its melting point?
What is Brittania metal?
How many oxides of tin are there?
P. 274. What is stannic acid?
What is *putty of tin?*
P. 275. *How is protochloride of tin formed?*
-With what other metal is cobalt usually found combined?
P. 276. Is this metal capable of becoming magnetic?
What is *smalt?*
P. 277. What peculiarity is there in writing done with solution of chloride of cobalt?
Is nickel usually found combined with iron of meteoric origin?
What is said of its color, malleability, &c.?
Is it capable of becoming magnetic?
Is it fusible?
P. 278. What use is made of it in the arts?
How is arsenic obtained from its ores?
What are some of its properties?
At what temperature is it sublimed?
What is said of its odor?
P. 279. What name is often given to metallic arsenic in commerce?
What is the *white arsenic* of commerce?
What two varieties of it are known?
P. 280. What use is sometimes made of it?
What symptoms first appear after it has been taken?
What substance is said to be a good remedy for it?
P. 281. What is the first test for arsenic that is described?
What is the second test?
P. 282. How does hydrosulphuric acid indicate the presence of arsenic?
What is said to be the most decisive test?
What is the proper method for obtaining the metal?
P. 283. What is Marsh's test?
Do any other metals give the same indications?
How may they be distinguished from arsenic?
P. 284. Is it necessary in using this test to be particularly careful to have the materials pure?
What use is made of arsenious acid in the arts?
P. 285. *What is the composition of arsenic acid?*
How is arseniuretted hydrogen prepared?
What two sulphurets of arsenic are there?
P. 286. In what minerals is chromium found?
From what circumstance has it derived its name?
What is the appearance of the metal?
P. 289. Is antimony ever found native?
What is *regulus of antimony?*
How may the metal be obtained from its sulphuret?
What are its color and texture?
Does it readily oxydize in the open air?
P. 290. Is antimony used in the arts?
P. 292. What is the appearance of bismuth?

At what temperature does it fuse?

P. 294. From what ore is most of the copper of commerce derived?

How is it distinguished from all other metals except titanium?

What is its specific gravity?

Is it oxydized in a dry atmosphere?

P. 295. Of what is *German silver* composed?

P. 296. What is the composition of dinoxide of copper?

P. 297. What ore of lead is used exclusively in extracting the lead of ommerce?

What other metal is usually associated with it?

P. 298. What is the color of lead?

Is it acted on by pure water?

What is said of the protecting influence of some salts?

P. 299. What is the design of a *solder*?

Of what is fine solder composed?

Of what are printers' types composed?

P. 300. What is *litharge*?

What use is made of it?

P. 301. From what countries is mercury obtained?

P. 302. What is the chief ore of mercury?

How is this metal distinguished from all others?

At what temperature does it congeal?

What is its density?

What are the only acids that act upon it?

For what purposes is it used in the arts?

P. 303. What is an amalgam?

P. 304. What is the common name for peroxide of mercury?

What is the composition of *calomel*?

P. 305. What use is made of it?

What is the common name for the bichloride?

P. 306. What are its effects when taken into the stomach?

What substance serves as a remedy by forming with it an insoluble compound?

P. 307. How may calomel and corrosive sublimate be distinguished from each other?

What is the composition of *cinnabar*?

To what use is it applied?

P. 308. Is silver found native?

What is said of the color of silver?

P. 309. Does it rust by exposure to the air?

What acids dissolve it?

What occasions the tarnish, seen upon articles of silver which are in constant use?

P. 311. Was gold known to the ancients?

In what state is it always found?

What countries produce it most abundantly?

By what process is it usually separated from its ores?

P. 312. What is its color?

What is said of its malleability?

What is its specific gravity?

How is the purity of gold and silver estimated?

What is the fineness of standard gold?

Is it oxydized by exposure to the air?

What substance dissolves it?

P. 313. What effect has the presence of other metals upon its malleability?

What metal is usually found combined with native gold?

P. 315. How may sulphuric ether be made to dissolve gold?

How is *purple of Cassius* formed?

P. 316. When was platinum discovered?
What other metals are usually in combination with it?
What is its specific gravity?
Is it affected by exposure to air or moisture?
P. 317. For what purposes is it used in the arts?
P. 320. Do acids and alkalies unite with elementary substances?
What is said of the electrical energies of acids and alkalies?
What substances are now considered acids?
What is a base?
P. 321. What two classes of salts were early recognized?
What is a *sulphur salt?*
What are *sulphur acids* and *sulphur bases?*
What are the haloid salts?
What are the four orders of salts?
P. 322. Can the number of salts be determined?
What is the state of most of the salts at common temperatures?
When is a salt said to be *deliquescent?*
Are all the salts soluble in water?
P. 323. What is meant by the *water of crystalization* often contained in salts?
P. 326. How will the salts be classified for further description?
P. 327. How may a sulphate in solution always be detected?
What sulphates are found abundantly in nature?
P. 329. What is the common name for sulphate of soda?
What use is made of it?
P. 320. What are some of the names applied to sulphate of lime?
How is it prepared for use in *stucco* work?
P. 331. What is *Epsom salt* composed of?
Why is it called by this name?
What are *green vitriol*, *blue vitriol*, and *white vitriol?*
P. 332. What is the composition of *alum?*
P. 333. What different alums are there?
How may the nitrates be prepared?
P. 334. How are they affected by heat?
What is the common name of nitrate of potassa?
How is this salt formed in this country?
P. 325. What is the explanation of the action of gunpowder when ignited?
P. 336. What is the common name for nitrate of silver?
P. 337. What use is sometimes made of it?
What color is produced by it upon organic matter by the action of light?
How are the chlorates affected by a red heat?
P. 338. How is chlorate of potassa formed?
To what use is it applied?
What is the composition of common *bleaching salt?*
P. 339. For what purpose is it used in the arts and in medicine?
What acid enters into the composition of the phosphates?
What three tribasic phosphates of soda and water are there?
P. 342. For what are the salts of chromic acid distinguished?
How is chromate of potassa formed?
What use is made of bichromate of potassa?
P. 343. What is *chrome yellow?*
How are the borates known?
What is the common name for biborate of soda?
What is it used for?
P. 344. How may the carbonates be known?
P. 345. From what is the potash of commerce obtained?
What is *pearlash?*
P. 346. What is the composition of *sal-æratus?*

How is the carbonate of soda procured?
P. 347. What use is made of bicarbonate of soda?
What is the *sal-volatile* of commerce?
P. 349. What compounds only are included in the order of hydro-salts?
What is the composition of *sal ammoniac?*
P. 350. What compounds are included in the order of sulphur salts?
P. 351. What is hydrosulphuret of potassium composed of?
P. 352. *What compounds are included in the order of haloid salts?*

PART III.

ORGANIC CHEMISTRY.

P. 354. What does the department of Organic Chemistry comprehend?
What are the usual elements of organic matter?
What is said of the number of simple atoms they usually contain?
Do the elements of organic bodies combine with each other in definite proportions?
P. 355. Why are organic bodies, when life has become extinct, prone to spontaneous decomposition?
May organic compounds be imitated by art?
P. 356. What is a compound radical?
P. 359. What three elementary principles enter into the composition of vegetable bodies?
What are meant by proximate and ultimate principles?
What are vegetable acids?
What is meant by a polybasic acid?
P. 360. In what vegetable is oxalic acid found ready formed?
P. 361. How is this acid formed artificially?
May it be formed from other substances besides sugar?
What are its effects when taken into the stomach?
For what salt used in medicine has it sometimes been mistaken?
What substance should be taken as a remedy when it has been accidentally swallowed?
P. 362. Is acetic acid found ready formed in some plants?
P. 363. What is common vinegar?
What substances may be made to produce acetic acid?
How may the concentrated acid be best procured?
P. 364. What are some of its properties?
What is common *sugar of lead?*
P. 365. What is the composition of *verdigris?*
How is it prepared?
P. 366. From what is benzoic acid procured?
P. 367. What plants contain malic acid?
What fruits contain citric acid?
What use is made of it?
P. 368. In what is tartaric acid found?
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What is cream of tartar?
P. 369. In what is gallic acid found?
From what is it usually prepared?
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What are some of these alkalies?
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What are some of its properties when pure?
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What two vegetable alkalies are usually found associated in the different varieties of Peruvian bark?
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Are its alkaline properties well marked?
What name is often applied to sulphate of quinia?
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What is its state at ordinary temperatures?
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What is its composition?
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From what property does this acid derive its name?
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Does cyanuric acid differ in its composition from the two preceding?
From what may hydrocyanic acid be procured?
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What are its effects upon animals?
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Is it used in medicine?
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What is this substance sometimes called?
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By what name is it known in commerce?
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By what means is it procured?
Does it crystalize?
What effect is produced upon it by boiling water?
What is the best test for starch?
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How is it prepared from cane juice?
How is the raw sugar purified?
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What proportion of alcohol is contained in brandy, rum, gin, &c.?
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What are the three stages of fermentation, or the three fermentations?
What is the product of the saccharine fermentation?
In what does the operation of malting consist?
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What are the conditions necessary to produce this fermentation?
Is sugar the only substance capable of fermenting?
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What is produced during the acetic fermentation?
Is atmospheric air necessary to produce this fermentation?
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How is sulphuric ether formed?

P. 390. What are some of its properties?
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How is hyponitrous ether formed?
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What is it sometimes called?
P. 395. How are oils characterized?
How are they divided?
In what parts of plants are the fixed oils usually contained?
Are they generally liquid or solid?
What three principles are they generally composed of?
What are siccative or drying oils?
P. 396. Why is litharge sometimes mixed with paints?
Do the fixed oils combine with water?
What is *soap?*
What three varieties of soap are there in commerce?
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What occasions the odor of aromatic plants?
How may any adulteration of them with a fixed oil be detected?
From what is oil of turpentine procured?
What is its composition when pure?
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From what is camphor obtained?
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What are the resins?
In what liquids are they in general soluble?
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What are some of its properties?
Is it soluble in water?
Into what two varieties may coal be divided?
How is bituminous coal distinguished?
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Where in the United States is anthracite found in great abundance?
What substances are used in the preparation of illuminating gas?
How is coal gas formed?
Is the quality of the gas always the same?
Is this gas sometimes found issuing from the earth?
P. 402. What is said of the care required in preparing oil gas?
Why does coal gas require to be cleansed before use?
Do we find great diversity in the colors of vegetable substances?
Is coloring matter often found in a separate state?
How are coloring matters called *lakes* usually formed?
What is the use of a *mordant?*
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What substance is used for coloring blue?
P. 405. What is meant by germination?
What are the conditions necessary to healthy germination?
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From what source do plants derive their carbon?
Is light necessary for the proper growth of plants?
P. 407. Does nitrogen serve an important purpose in plants?

Do plants probably derive nitrogen from the atmosphere?

Are inorganic substances found in plants?

P. 408. Do plants show a disposition to absorb some salts and reject others?

In what plants is potassa usually found?

Why are bone-dust and wood-ashes found to be excellent manures for promoting the growth of wheat?

What is the design of manures?

Upon what is the great advantage of organic manures supposed to depend?

P. 409. In what parts of plants is nitrogen chiefly to be found?

What are the chief elements of animal substances?

P. 410. What change immediately takes place in animal substances at death?

Where is fibrin found?

Into what parts of the animal does albumen enter?

From what is liquid albumen best procured?

P. 411. What effect is produced upon it by heat?

In what parts of the body is gelatine found?

P. 412. What well-known article of commerce is prepared from gelatine?

What are bones chiefly composed of?

What effect is produced upon bones by heating them in the open air?

P. 413. What are the teeth composed of?

What substance forms the chief part of the tendons?

P. 414. Are the animal oils and fats analogous in their composition to those of vegetables?

P. 415. How is the blood distinguished from other animal fluids?

What is its specific gravity?

P. 416. What change takes place in it when first drawn from the system?

What is the coloring principle of the blood?

P. 417. Is iron an essential principle of hematosine?

In what does the coagulation of blood consist?

Is the process influenced by the air or by other substances?

P. 418. May the blood be diseased?

What difference is observed in the color of the blood in the veins and arteries?

How is the change from the venous to the arterial state effected?

P. 419. Is the coloring matter of the blood particularly concerned in the change?

What gas is absorbed by the air in the lungs, and what gas is given off?

Is it known where the carbonic acid gas is formed?

Does the arterialization of the blood depend entirely on the influence of the atmosphere?

P. 420. May the same changes be produced upon blood after it is drawn from the system?

P. 421. Does nitrogen serve any important purpose in respiration?

Is there a close connection between the functions of respiration and the development of animal heat?

P. 422. When the blood circulates sluggishly, is the same quantity of oxygen required as at other times?

By what substances are the phenomena of digestion produced?

By what organs is the saliva secreted?

P. 423. What is the use of the saliva?

Where is the gastric juice secreted?

What is said of the solvent power of this liquid?

THE END.

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